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LIFE CYCLE COSTING OF AN EMERGING TECHNOLOGY: THE FIBER OPTICS --ETC(U)

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LIFE CYCLE COSTING OF AN EMERGING TECHNOLOGY:
THE FIBER OPTICS CASE

by

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The System Acquisition Research Program

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As significant technological advances in fiber optics and optical data transmission methods are being made, it is necessary to develop appropriate methods for estimating life cycle costs for alternative coaxial/twisted pair wire and optical fiber avionics.

In Volume One measures of effectiveness are suggested for each alternative system. An approach, which structures the technological and demand uncertainties of fiber optics, is developed through scenarios as a means of

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relating cost and effectiveness. It is suggested that Delphi and experience curve techniques be used in conjunction with ordered scenarios as a technological forecasting technique for estimation of life cycle costs of fiber optics. In addition, a review of the historical and technological background of fiber optics and their application to the Naval Electronics Laboratory Center (NELC) A-7 Airborne Light Optical Fibert Technology (ALOFT) Program is included.

ACKNOWLEDGEMENT

This technical report contains the culmination of a research effort of four Naval Postgraduate School thesis students working under the guidance of Professor Carl R. Jones.

In early 1975 the Naval Electronics Laboratory Center (NELC), San Diego, California, sought the assistance of Professor Carl R. Jones to aid in an economic analysis of the NELC A-7 ALOFT program. Two NPS students, J. M. McGrath and K. R. Michna, began the research effort by writing their Master's thesis, "An Approach to the Estimation of Life Cycle Costs of a Fiber-Optic Application in Military Aircraft," in September 1975. The follow-up to that thesis was, "The A-7 ALOFT Cost Model: A Study of High Technology Cost Estimating," authored by R. L. Johnson and E. W. Knobloch.

Independent of the two thesis efforts was an analysis of the emerging fiber optics industry and a fiber optics cost collection effort by E. W. Knobloch.

Professor Carl R. Jones directed an editing by E. W. Knobloch of the total research effort and the publication of this report. As such, it supercedes the two theses discussed above.

The authors wish to express their sincere gratitude to LCDR John Ellis, the A-7 ALOFT program manager, and Mr. Roger Greenwell, the A-7 ALOFT operations analyst who both gave generously of their time, information and funding. Without their continued support, this report would not have been possible.

ABSTRACT

As significant technological advances in fiber optics and optical data tranmission methods are being made, it is necessary to develop appropriate methods for estimating life cycle costs for alternative coaxial/twisted pair wire and optical fiber avionics.

In Volume One, measure of effectiveness are suggested for each alternative system. An approach, which structures the technological and demand uncertainties of fiber optics, is developed through scenarios as a means of relating cost and effectiveness. It is suggested that Delphi and experience curve techniques be used in conjunction with ordered scenarios as a technological forecasting technique for estimation of life cycle costs of fiber optics. In addition, a review of the historical and technological background of fiber optics and their application to the Naval Electronics Laboratory Center (NELC) A-7 Airborne Light Optical Fiber Technology (ALOFT) Program is included.

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VOLUME ONE

I. INTRODUCTION

Present day avionics in military aircraft utilize twisted shielded pair wire and/or coaxial cable to transfer signal data. These data link subsystems reflect post-World War II state of the art in electronic development. Electronic signal transmission by this means exposes avionics to potential operational degradation and damage because of the suscepti-bility of metallic conductors to electromagnetic interference, radio-frequency interference, and nuclear-generated electro-magnetic pulse. Other sources of electronic interference such as cross-talk, ground looping, reflection, and short-circuit loading also degrade system operation.

A recent technological breakthrough in the field of fiber optics has made fiber-optic data link applications technically feasible, and perhaps desirable, for use in military aircraft avionics systems. Fiber optics technology does offer several significant advantages for avionics data link subsystems. The primary advantages are that it: (1) is not susceptible to electromagnetic interference (EMI) nor to electromagnetic pulse (EMP) associated with a nuclear blast; (2) does not generate EMI; (3) is isolated from ground plane signals; and (4) is capable of higher data rate transmission.

As a result of feasibility tests and demonstrations conducted or sponsored by Naval Electronics Laboratory Center (NELC), San Diego, approval was gained from the Assistant Secretary of the Navy for Research and Development to implement a two-year feasibility program to install fiber optics components (fiber-optic cables, light sources, light detectors, and connectors) in place of standard twisted pair wire and coaxial cable for selected components of the Navigation/Weapons Delivery System (N/WDS) of an operational A-7E Corsair II light jet attack aircraft. The program, called the A-7 Airborne Light Optical Fiber Technology (ALOFT) Demonstration, is a feasibility demonstration to determine the information transfer capability of an aircraft avionics system through point-to-point applications of fiber optics.

Concurrent with the A-7 ALOFT Demonstration checkout, test and evaluation, an economic analysis was desired by NELC for the two alternative systems; coaxial cabling and fiber-optic cabling. These two alternatives, together with their associated components, will hereafter be referred to as "coax" and "fiber optics."

The basic format of an economic analysis involves the determination of the cost and effectiveness of competing alternatives. A life cycle cost model, as defined by NELC and Naval Postgraduate School (NPS) students is used as the costing basis for the two alternatives.

The McDonnell Aircraft Company (MCAIR) has been contracted by NELC to perform the costing of the coax alternative. MCAIR will also determine the measures of effectiveness for both the coax and fiber optics systems. Naval Postgraduate School students have performed the preliminary costing effort of the fiber optics alternative. NPS students and NELC systems analysts personnel will coordinate future efforts toward the desired objective of numerical estimation of fiber optics life cycle costs.

As a baseline for Volume Two, the authors have discussed the historical and technological background of fiber optics, as well as, the background of the A-7 ALOFT Demonstration. A general discussion of a cost-effectiveness analysis is presented together with possible measure of effectiveness (MOEs) for data transfer.

Since fiber optics cost data is either non-existent or available only on a prototype basis, the authors' basic approach to costing fiber optics is done through scenarios. Scenarios offer a means of ordering the uncertainties of an emerging technology. They define the possible futures of the fiber optics industry and its related technology. Three sample scenarios developed by the authors provide specific time-related estimates as to civilian/military demand, growth rates,

standardization and technological development. These representative scenarios are meant to provide the basis from which cost estimates could be made.

Two exploratory techniques, Delphi and experience curves, are discussed as they pertain to the costing of an emerging fiber-optic technology. Sample Delphi questionnaires are developed as a means of soliciting forecasts from a panel of experts in order to deal with specific uncertainties associated with fiber optics manufacturing and applications. The information gained from the Delphi surveys can be used to refine the estimates contained in the scenarios as well as minimize the number of possible scenarios.

Experience curve evidence is discussed as a means for forecasting unit cost reduction as the fiber optics experience base accumulates. The information required for using experience curves is provided by the scenarios. Experience curves can then be used as a means of predicting the cost behavior of components relating to fiber-optic technology.

It is shown by the authors that these techniques; scenario-writing, Delphi and experience curves, can be combined as a cost-predictive method to estimate component prices of an emerging technology such as fiber optics. These techniques then provide a means of estimating costs for the life cycle

cost model elements used in a cost-effectiveness study. Not only have the fiber-optic component procurement costs been estimated, but the costs to operate and maintain a fiber-optic system will also be determined through future efforts.

This volume, then, is the first step in developing a cost-effectiveness study which could aid in making decisions concerning the use of coax or fiber optics in the next series of military aircraft to be designed and built (VAX, VFX, VPX, etc.).

It is the basic conclusion of the authors that the emerging fiber-optic technology deserves full and continuing effort and attention by research and development (R&D) agencies. Even if the results of initial cost-effectiveness studies are such that the decision is made to not use fiber optics in the next generation of aircraft, the authors feel that it would be a mistake to cut back or reduce fiber optics R&D funding. The military services are pursuing extremely meaningful and productive research and development in a field containing great potential for future benefits to the military services in general. It is expected that fiber optics will be used in some future generation of military aircraft and weapons systems. These future weapons systems would be the beneficiaries of today's efforts from the development of this emerging technology.

II. BACKGROUND

Man has employed optical means in military communications since ancient times. Early writers, such as the Greek historian Polybius (c. 205-125 B.C.), refer to the employment of visual signaling, including flags and smoke signals. Flag and light codes for naval communications were developed by sea forces during the sixteenth century. In 1875, the U.S. Navy began experimenting with electric lights for signaling. By 1916, Rankine had patented a voice communicator utilizing a vibrating mirror to modulate the optical carrier. The Navy developed a cesium vapor lamp which could be amplitude-modulated electrically at voice frequencies in 1944. Despite considerable effort and ingenuity, however, practical systems were limited to audio bandwidths until about 1961. By 1970, three advances of potential significance were reported: the development of the first injection laser which operated continuously at room temperature, the development of the first continuously operating dye laser, and the production of the first low-loss fiber optics transmission lines. These, and other electro-optical advances, such as light emitting diodes (LEDs), helped set the stage for fiber-optic communications systems. (79)

While visiting England in 1970, Dr. John M. Hood, a former student of H.H. Hopkins, recognized the suitability and timeliness of fiber-optic techniques for naval and military

applications. Upon his return from England, he was instrumental in having a Fiber Optics group established in the Electromagnetics Technology Department at NELC. The group, funded by internal research and development funds, was dedicated to the development of a practical technology for meeting the problems arising from the specific uses that fiber optics offers to the Navy. It was clear that a natural and obvious application was to improve the internal data links of military aircraft. It was also recognized that the potential for shipboard use was just as great. By mid-1971, various agencies of the Department of Defense (ONR, ARPA, NAVELEX and NAVAIR) had committed funds for continuing fiber-optic research. In April 1973, a Fiber Optics Development Plan was promulgated at NELC, setting forth a program for identifying and meeting the Navy's needs in the fiber optics field. This plan then became the official NAVAIR-NAVELEX development plan. It has since been superseded by the proposed DOD Tri-Service Technical Application Area Plan for Fiber Optics Communications Technology, dated 25 March 1975.

In January 1973, NELC entered into a contract with the Federal Systems Division of IBM Corporation under contract number N00123-73-C-1665 for the design, fabrication and

laboratory testing of a high speed, multiplex fiber-optic data link to interconnect the tactical computer and head-up display from an A-7 aircraft. The work was performed at the IBM Electronics Systems Center at Owego, New York, during the period February to May, 1973. The final report was completed in June 1973 by H.C. Farrell and R.N. Jackson. (32) In particular, the tests, made on the link between the ASN-91 computer and the Head-Up Display (HUD) took the form of performance comparisons between the fiber-optic link and the original conventional shielded wire cable, as well as experiments on special properties of the optical link. The results were conclusive: in a noise-free environment there was no detectible difference in performance between the two types of interfaces; in the presence of an electrical noise generator, however, the output display was unaffected when the signal was received via the optical channel, but it incurred serious deterioration when the shielded cable was used. Part of the laboratory tests in this contract tested the link through the full requirements of MIL-STD-461 and MIL-STD-462 (military standard specifications on Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI). These tests results were the first quantitative validation that fiber optics were definitely immune to RFI and EMI. (32)

The results of the IBM tests were made known to program review officials in the Navy Department and the Department of Defense. These officials recognized the need of a major feasibility demonstration to design and implement fiber-optic links at a full scale system level for test and evaluation. At this time, NELC made a proposal to Commander, Naval Air Systems Command (NAVAIR), for a two year program to install fiber optics in place of standard twisted-pair and coax cabling in the navigation/weapons delivery system (N/WDS) of an A-7 aircraft for test demonstration and evaluation purposes. Subsequent to this request, Dr. Malcolm R. Currie, Director of Defense Research and Engineering, submitted a memo, dated 6 August 1973, to the Assistant Secretary of the Navy for Research and Development in which he expressed confidence in the role of fiber optics technology for naval applications and thereby urged prosecution of a program for exploiting it. (21)

This request culminated in approval by the Assistant Secretary of the Navy for Research and Development and subsequent funding-go-ahead by OPNAV 982 and AIR360 for the implementation of the A-7 Airborne Light Optical Fiber Technology (ALOFT) Demonstration. The project was initially funded in March 1974 under AIRTASK A360360G/003C/4W41X1-001. (32)

In July 1974, the Chief of Naval Material, assigned the Naval Air Systems Command lead responsibility through

FY 1976 for the development of the fiber optics technology to fulfill military systems needs and applications. Commencing in FY 1977, the Naval Electronics Systems Command is designated to assume lead responsibility of the fiber optics development program. (17)

A. NELC A-7 ALOFT Demonstration Approach

As soon as the AIRTASK was received by NELC in March 1974 to initiate the ALOFT Project, NELC managers and engineers consolidated plans and objectives into a formalized Development Approach. The project was to consist of a two-year program with a milestone schedule as outlined in Figure 1-II-1. The major project phases were as follows:

(1) A six-month system analysis and design effort to be performed in part under NELC contracts to define the system performance requirements, to design the system, and to provide a system installation plan.

(2) A six-month contractual effort to fabricate and checkout the demonstration system in the contractor's system integration laboratory.

(3) A three-month test and evaluation program of the demonstration system while installed in an A-7 ground simulator.

A-7 Airborne Light Optical Fiber Technology Demonstration (ALOFT) Milestones

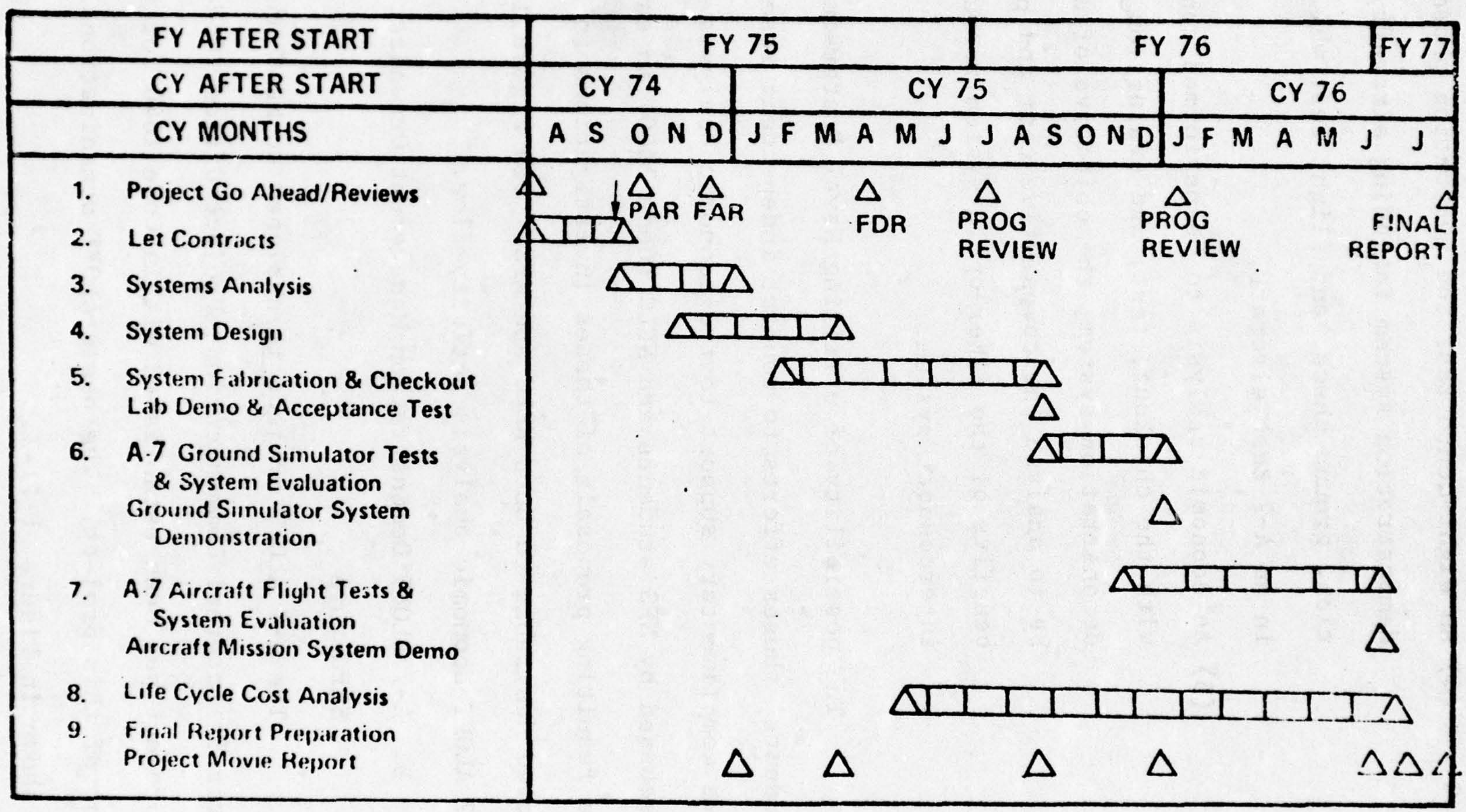


Figure 1-II-1 A-7 ALOFT Demonstration milestones

(4) An eight-month test and evaluation phase of the demonstration system including aircraft modification, ground check, and flight test while installed in an A-7 test aircraft.

(5) An economic analysis to be performed concurrently with with the checkout, test, and evaluation of the demonstration system; the objective of which will be to analyze the comparative cost and performance benefits of the fiber-optic system versus a wire interconnect system.

The possibility of utilizing Naval Postgraduate School students' theses efforts to conduct independent research and give complimentary support to the economic analysis was first discussed by NPS students and NELC (Code 1640) in early 1974. The resulting proposals of theses investigations in this area proved desirable to both NELC and NPS. See Figure 1-II-2 A-7 ALOFT economic analysis activity flow.

B. A-7 ALOFT Demonstration Management Organizational Structure

The A-7 ALOFT project is assigned to NELC under the Aircraft Internal Communications Project Office, Code 1640. A project has been established within Code 1640 for the management of this project. The basic ALOFT organizational structure is shown in Figure 1-II-3.

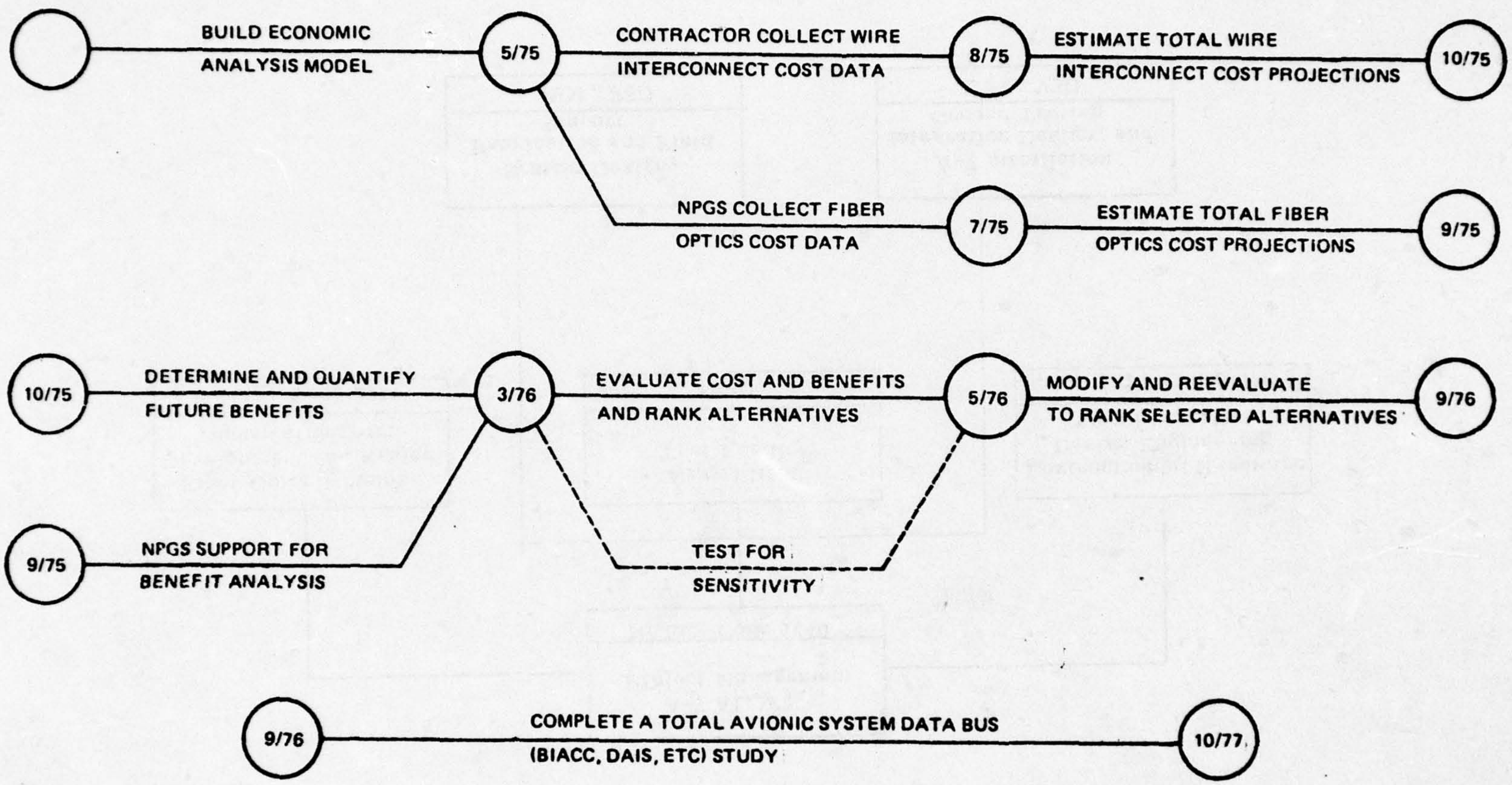


Figure 1-II-2 A-7 ALOFT economic analysis activity flow

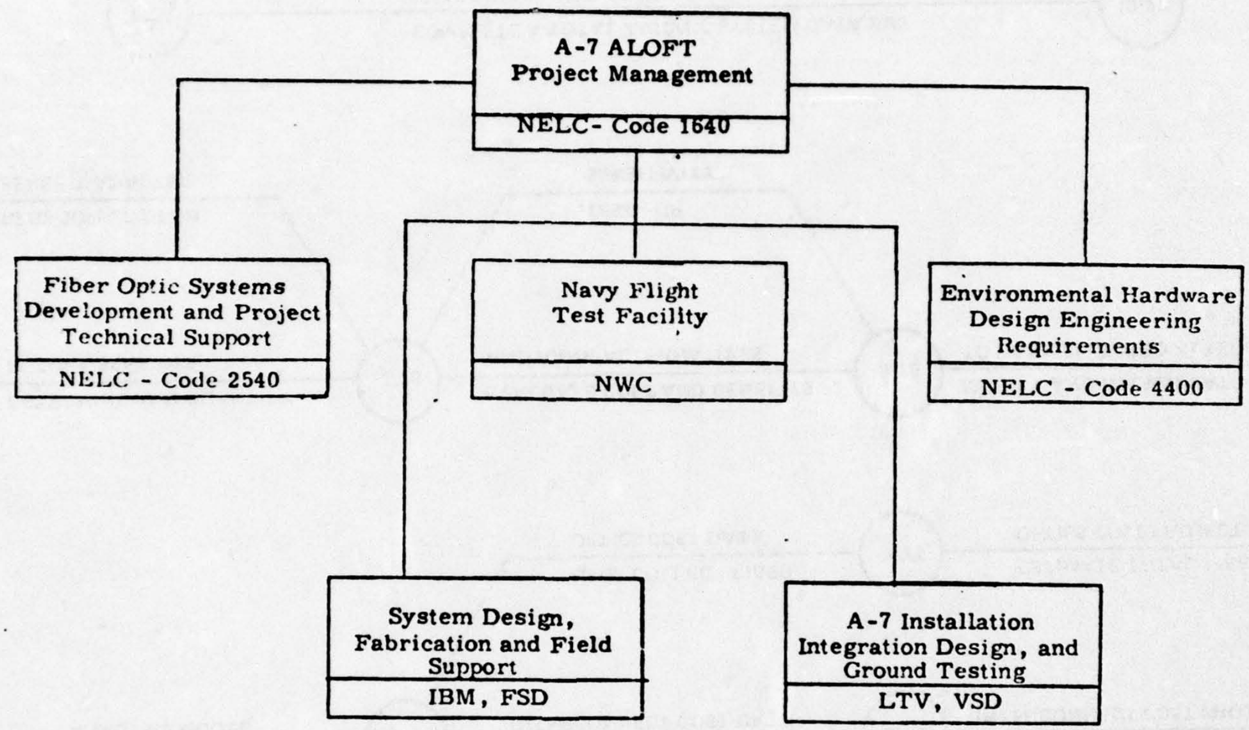


Figure 1-II-3 A-7 ALOFT Project Office organization structure

Under the current program effort in the A-7 ALOFT project the economic analysis function has been expanded to include some in-house management along with Naval Postgraduate support and contractual assistance. This structure is shown in Figure 1-II-4 which does not present the other organizations (see NELC-TD 369 for full organization).

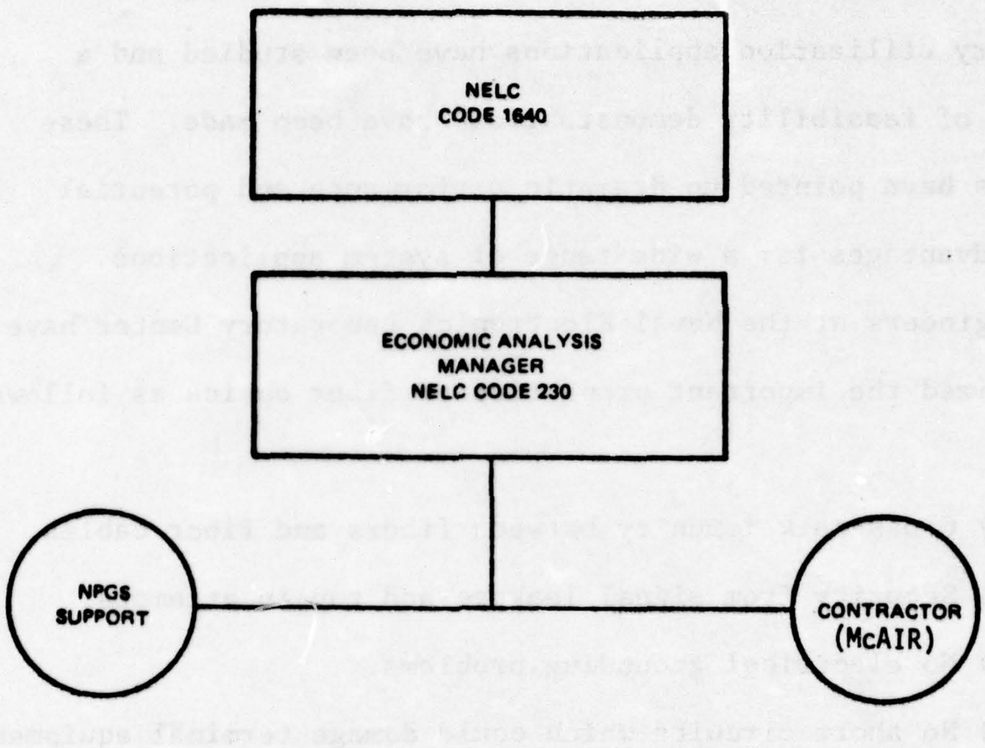


Figure 1-II-4 A-7 ALOFT economic analysis organization structure

III. FIBER OPTICS TECHNOLOGY AND ITS APPLICATION TO AIRCRAFT

A. GENERAL

Recent breakthroughs in fiber-optic technology have made the application of fiber-optic waveguide systems to military information transfer entirely possible and feasible. The area of avionics data transfer will possibly be the first major application or beneficiary of fiber-optic technology. Several military utilization applications have been studied and a number of feasibility demonstrations have been made. These studies have pointed up dramatic performance and potential cost advantages for a wide range of system applications.

Engineers at the Naval Electronics Laboratory Center have summarized the important properties of fiber optics as follows: [76]

(1) Cross-talk immunity between fibers and fiber cables.

(2) Security from signal leakage and tap-in attempts.

(3) No electrical grounding problems.

(4) No short circuits which could damage terminal equipment.

(5) No ringing problems.

(6) Large bandwidth for size and weight. The increase in bandwidth, combined with crosstalk/noise immunity, makes miltiplexing at high data rates possible.

(7) Small size, light weight (glass is 1/6 the weight of copper), and flexibility - thus, ease of installation.

(8) Potential low cost - when considering common factors such as size, flexibility, equivalent bandwidth, and manufacturing quantity. The strategic availability and cost of copper as compared to glass will play a future role.

(9) High temperature tolerance (500 to 1000°C).

(10) Safety in combustible areas and hazardous cargo areas (i.e., ammunition and fuel storage areas).

(11) No copper (strategic material).

(12) Potential Electromagnetic Pulse (EMP) immunity.

(13) RFI/EMI, noise immunity (glass, a dielectric, does not pick up nor radiate signal information.

B. FIBER OPTICS RELATED TECHNOLOGY

Certain principles, components and data link systems should be discussed before delving into the actual components used in the A-7 ALOFT project. This discussion is necessary for a greater understanding of a multiplexed fiber-optic system as a whole.

1. Attenuation

Light is attenuated as it moves down an optical fiber. Light is lost both to absorption and scattering in the fiber.

The absorption is determined primarily from the bulk of the glass from which the fiber is made. It converts light into heat. The scattering is due both to the bulk material and to fiber manufacturing defects. Radiation losses can also occur because of bends in the fiber, but losses are not significant unless bends are below a minimum bending radius.

Attenuation is a primary factor in the economics of fiber optics communication systems. It determines a system's repeater spacing, source output and detector sensitivity.

Attenuation can be measured in decibels because of the exponential nature of light attenuation in a fiber as given by:

$$P_o = P_i e^{-\alpha L}$$

where

P_o = power at receiving end of fiber

P_i = input power

α = extinction coefficient

L = fiber length

Extinction coefficients are sometimes used but decibels have become the accepted measure of attenuation.

$$\text{Attenuation (dB)} = 10 \log \frac{P_i}{P_o}$$

$$P_o = \frac{P_i}{10^{\text{dB}/10}}$$

The graph in Figure 1-III-1 shows how a low-loss fiber's attenuation changes with the wavelength used. It was obtained by Corning Glass researchers using one of their 4 dB/km low-loss fibers. (3)

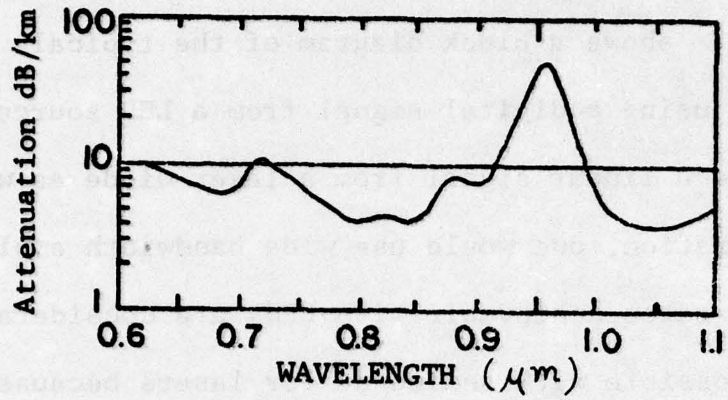


Figure 1-III-1 Attenuation as a function of wavelength in a recent Corning low-loss optical fiber

2. Modulation

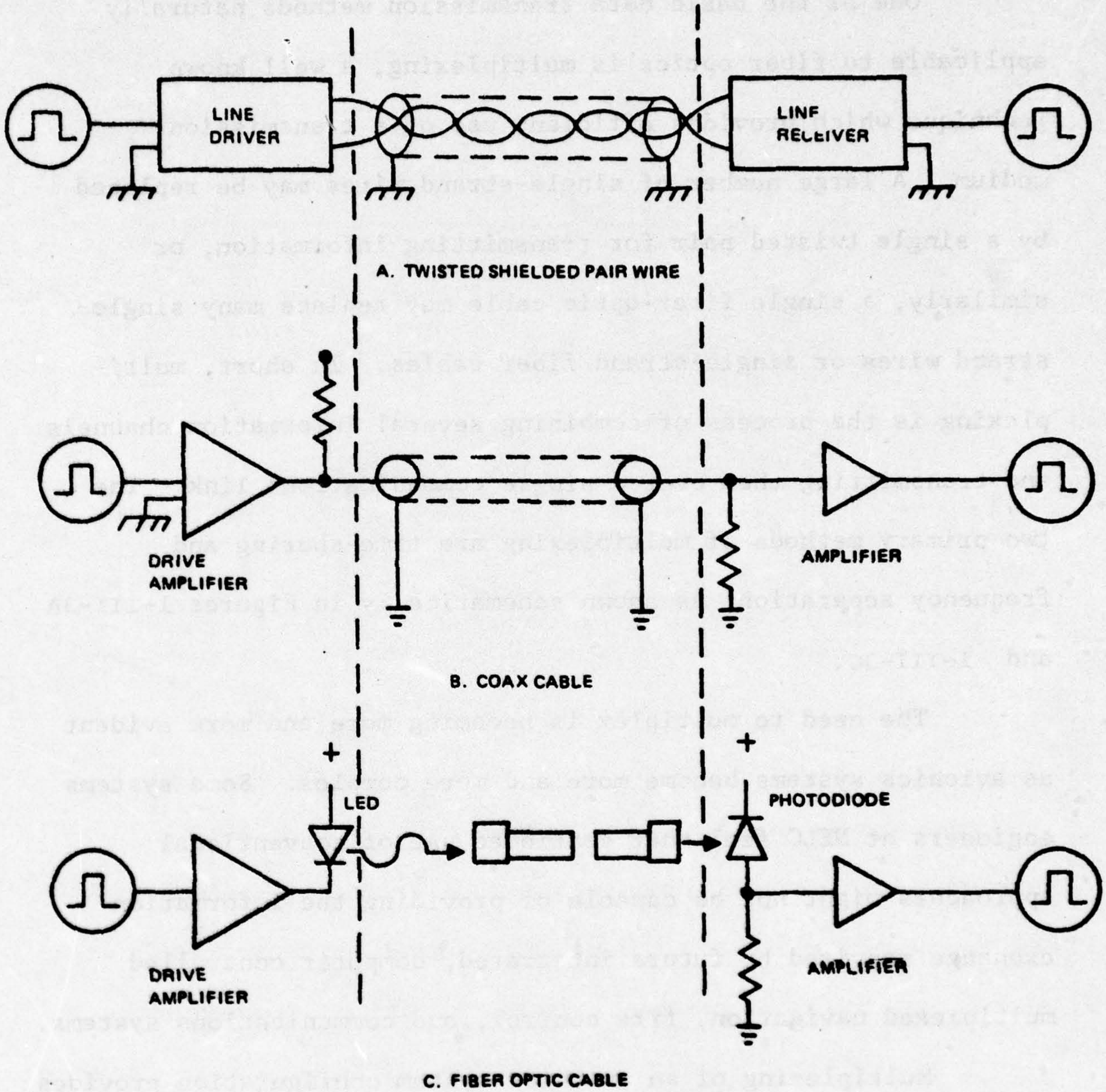
Light, as a carrier signal, from a light source such as a Light Emitting Diode (LED) must be modulated in order to carry data. The traditional modulation techniques of amplitude and frequency modulation require complex electronic circuitry, sine wave sub-carriers, etc., and increase costs, as well.

Digital Transmission is the easiest modulation mode to implement with optics. This results from the approximate linearity of LEDs in which the light output varies directly to

the drive current. The digital signal can be connected to the LED input port through a driver circuit or by digitally controlling the bias current to the LED. Where used as a binary on-off keying device, this technique causes a logic 1 input to give a logic 1 light output. (2)

Figure 1-III-2 shows a block diagram of the typical fiber-optic system using a digital signal from a LED source. The signal could be a linear signal from a laser diode as well. For high speed operation, one would use wide bandwidth amplifiers.

Modulation rates achievable with LEDs are considerably lower than those possible with semiconductor lasers because the rise times in the LED are limited by spontaneous minority carrier lifetimes, rather than stimulated minority carrier lifetimes, as in the laser. Nevertheless, very useful modulation rates are possible up to a few hundred megahertz (MHz). Assuming an acceptable fiber loss factor in the range of 50 dB/km, one finds a 200 MHz limit with fiber optics for a 300 meter length. This is primarily a function of the electro-optic devices available. Coax, on the other hand, is limited to 20 MHz for the same cable size and length, and a twisted pair wire pair to 1 MHz. (73)



Source: **NELC**

Figure 1-III-2 **Typical interface systems**

3. Multiplexing/Data Bus

One of the basic data transmission methods naturally applicable to fiber optics is multiplexing, a well known technique which provides efficient use of a transmission medium. A large number of single-strand wires may be replaced by a single twisted pair for transmitting information, or similarly, a single fiber-optic cable may replace many single-strand wires or single-strand fiber cables. In short, multiplexing is the process of combining several information channels and transmitting them over a single communications link. The two primary methods of multiplexing are time-sharing and frequency separation, as shown schematically in Figures 1-III-3A and 1-III-3C.

The need to multiplex is becoming more and more evident as avionics systems become more and more complex. Some systems engineers at NELC feel that continued use of conventional approaches might not be capable of providing the information exchange required by future integrated, computer controlled multiplexed navigation, fire control, and communications systems.

Multiplexing of an avionics system configuration provides advantages in several areas: reduced weight, increased flexibility, ease of modification, ease of maintenance, reduced life cycle costs (attributed to reduced maintenance and modification, irrespective of investment costs) and a higher survivability rate. (2)

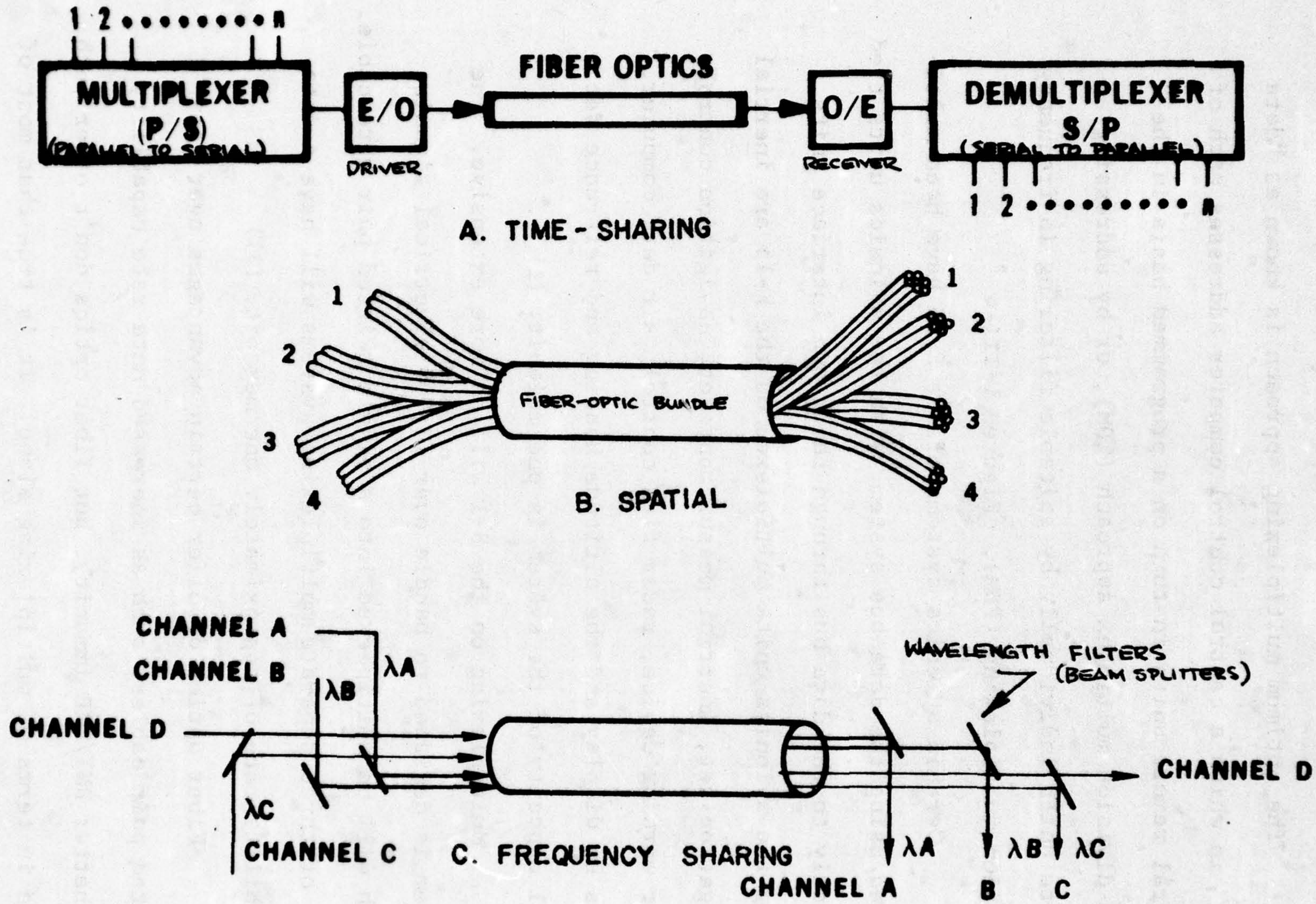


Figure 1-III-3 Data multiplexing

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The optimum multiplexing approach is known as "data bus," in which a central control computer addresses each of several remote units in turn on a programmed basis in the time division multiplex approach (TDM), or by addressing remote units individually by suitable filtering in frequency division multiplexing (FDM). Figure 1-III-4

Certain avionics systems of the F-15 have been multiplexed using the data bus system, with the avionics units tied directly to the data bus through their own interface units. Among the avionics units multiplexed on the F-15 are inertial navigation set, inertial measurement set, navigation control, radar warning device, radar fire control, air data computer, heads up display and the altitude heading and reference set. Total capacity of the system is one megabit. (1)

Multiplexing on the B-1 will be more extensive. The system is designed to handle over 12,000 electrical signals which will be multiplexed into a single twisted pair wire cable. Each of three separate multiplexing systems will have a data capability rate of approximately one megabit. (31)

Fiber optics do offer certain advantages over coax/twisted pair cables, such as increased data rate capability and better RMI/EMP immunity, but fiber optics don't offer much extra in terms of multiplexing alone. It is true that most of the advantages of multiplexing can be gained by using conventional

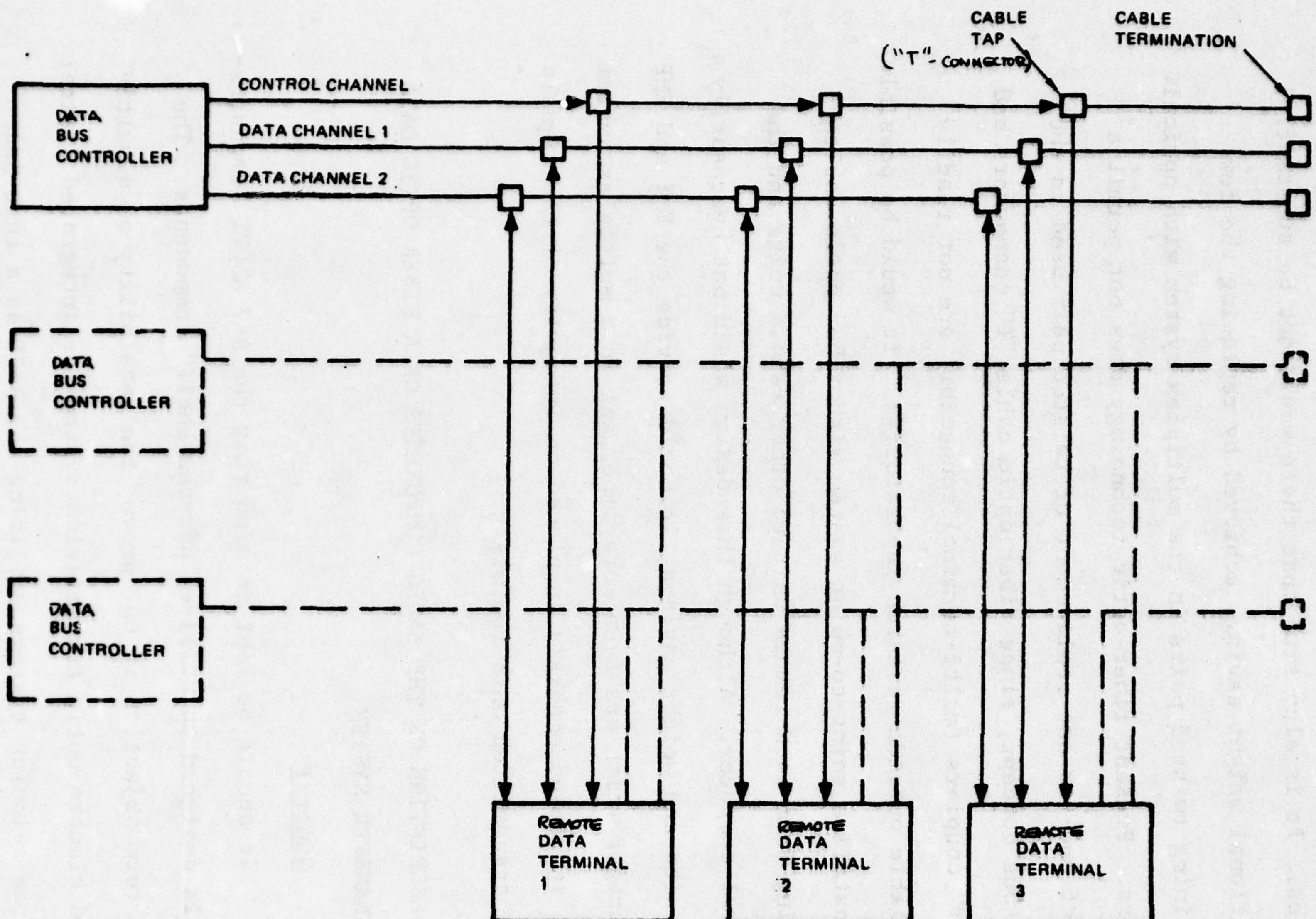


Figure 1-III-4. Typical aircraft data bus architecture

cables. It is also true that there would not be substantial additional weight savings achieved by replacing the few remaining twisted pairs in the multiplex system with optical fibers. Present fiber-optic technology does not permit a direct one-for-one replacement of twisted pair used in the data bus concept, since fiber optic cable "T" connectors and "star" couplers (multi-terminal connector) are not readily available outside research laboratories. It would be possible to install a point-to-point system with fiber-optic cables running from each remote unit to other remote units and the central computer. Although this design would not necessarily mean size and weight savings, it could provide the EMI and EMP advantages which are even more important in a multiplex system where increased emphasis is placed on integrity of the signals being transmitted on a few wires.

C. DESCRIPTION OF THE BASIC COMPONENTS OF A FIBER OPTIC DATA TRANSFER SYSTEM

1. General

It should be kept in mind that the A-7 ALOFT Demonstration is designed to utilize "off-the-shelf" components. The short term objective is to prove the feasibility of a multiplexed electro-optic transmission system for integrated digital airborne avionics systems utilizing the A-7E as a test bed.

The system, as designed, is a demonstration only and is not envisioned as being a design prototype for future generation avionics systems. Future fiber optics avionics systems would not necessarily be designed to incorporate all or any part of the present "off-the-shelf" technology of point-to-point systems, e.g., discrete circuits, and multimode fibers. Rather it is probable that future systems would be designed to incorporate improved LED or laser injected diodes, single mode fibers, integrated optical circuits and a data bus concept, etc.

2. Glass Fibers/Cables

Light is able to propagate through glass or plastic fibers because of the well known phenomenon of Total Internal Reflection (TIR). For this phenomenon to hold true it is necessary for certain conditions to exist. First, light rays must hit the entrance end at angles less than the critical incident angle, Θ_c, or otherwise be deflected from the desired course. Figure 1-III-5. Second, the fiber itself must have met exacting manufacturing standards to prevent surface imperfections which will cause absorption and scattering of light. In particular, metal ions such as iron, nickel or cobalt -- normally used to color glass -- should be eliminated because of their light absorptive characteristics. In addition, the fiber (or fiber bundles) should be designed so as to prevent leakage of light from fiber to fiber because of cross-coupling

effects. These effects are associated with the penetration of light into the surrounding low-density medium. The penetration depth is small, reaching at most 2 λ(λ =wavelength of transmitted light). Leakage is therefore significant only in sufficiently dense fiber bundles. (63)

A light ray undergoes a multitude of reflections even when propagating along a relatively short fiber. Calculations show that in a fiber about 50 microns diameter, there are upwards of 13,000 reflections per 1 meter of fiber length. (81)

To prevent leakage of light, fibers are coated with special materials which provide a high reflection coefficient. This material is usually a dielectric coating called the outer cladding. The outer cladding has an index of refraction (n) somewhat lower than the glass core. As a result, light rays are trapped in the core by reflection from the cladding, as shown in Figure 1-III-5. Note that the zigzag path slows arrival of some rays.

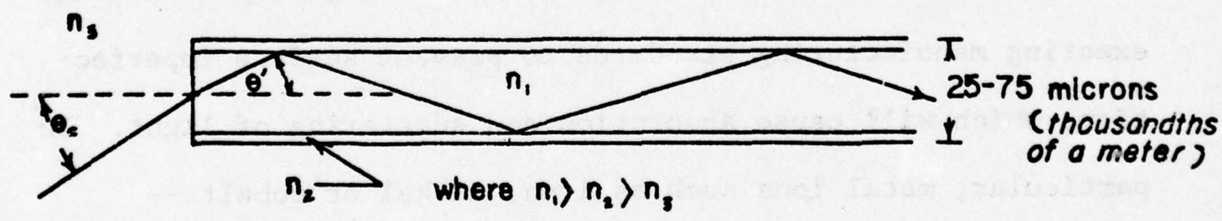


Figure 1-III-5. Typical glass-clad fiber. The optimum sheath thickness is approximately equal to the wavelength of transferred radiation.

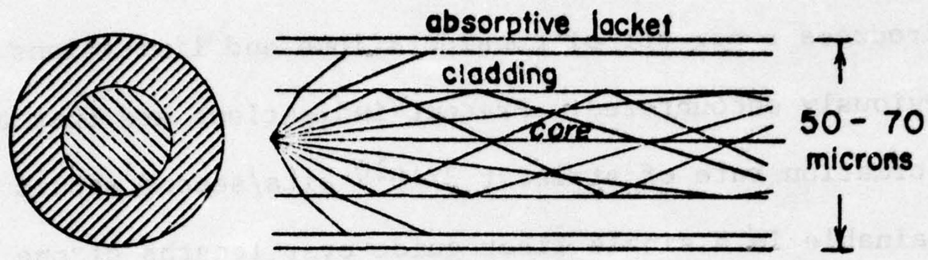


Figure 1-III-6. Large-core, solid-clad fiber. The diameter is slightly wider than a human hair.

Light rays that graze the cladding at shallow angles are reflected back into the core resulting in a zigzag path for some rays while other rays follow essentially straight lines along the core. Figure 1-III-6. This zigzagging can create problems in timing for long distance communications by distorting the on-off digital pulses used for high density communications. This particular problem, however, would not be a factor in short distance data link systems in aircraft.

One method of eliminating the delay problem is to make the central core so small (a few microns) that only a single ray can pass through it. Figure 1-III-7. Such fibers are called "single mode" fibers and must be used with lasers.

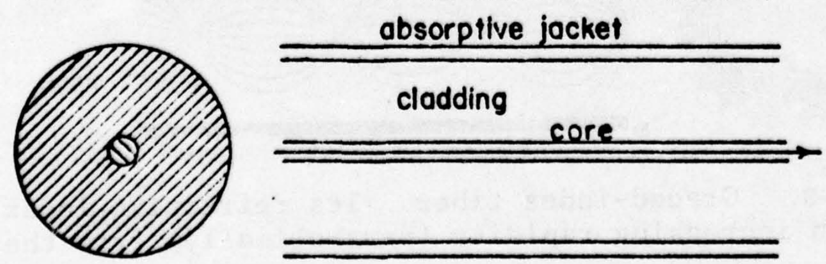


Figure 1-III-7. Single-mode fiber. Core diameters are only a few microns, typically on the order of the light wavelength.

Transmission of a light pulse down a single fiber introduces a new set of considerations and limitations not previously encountered. Present indications are that an information rate of at least $3X10^{10}$ bits/second should be attainable in a single fiber guide over lengths of one kilometer. (82) Present techniques for utilizing single mode transmission incorporate laser-injection-diodes as a light source. However, one of the most troublesome problems is splicing (joining) two fibers together such that the signal can travel on without distortion or undue attenuation.

Graded-index fibers have an index of refraction which gradually becomes lower from the center outward. Instead of travelling in zigzag paths, light rays follow a roller-coaster-like sinusoidal path. Figure 1-III-8. The gradually changing refractive index actually speeds up light rays travelling farther from the central axis. This results in light rays arriving at nearly the same time, even over long distances, thus minimizing "smearing" (nodal dispersion) associated with

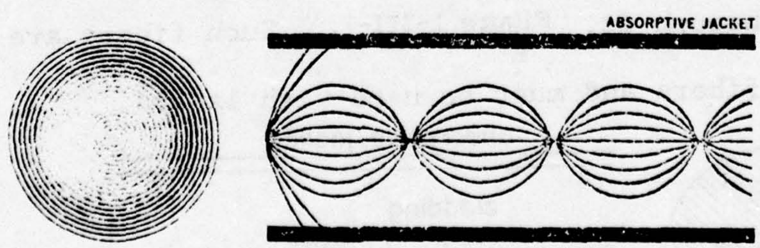


Figure 1-III-8. Graded-index fiber. Its refractive index decrease with increasing rapidity (parabolically) from the center outward.

other fibers. The most common graded-index fiber, known as SELFOC (self-focusing), was developed by Nippon Sheet Glass Company, Ltd., of Japan.

SELFOC offers several advantages over the total internal reflection fiber including larger bandwidth with no appreciable wave form distortion, and the capacity for single fiber imaging and special multiplexing. The disadvantages are a lower flexibility than the TIR fiber due to a larger diameter and the difficulty in bundling SELFOC fibers effectively. (1)

SELFOC fibers are possible candidates for an optical data link because of their major advantage in their capability to preserve the mode pattern and the fact that the absence of a core-cladding interface eliminates the potential source of defects from impurities and scattering centers which may occur during fiber drawing. However, in the opinion of R.L. Ohlhaber of IIT Research Institute, the typical high attenuation (approximately 200 dB/km) as well as complex fabrication procedures and their associated cost all but eliminate SELFOC for long distance communication at the present time. (82)

Individual fibers may be bundled into a cable (multimode) no thicker than the lead of a pencil as shown in Figure 1-III-9. Fiber bundles have enormous signal-carrying capacity for their size. Each fiber in the bundle, carrying signals as rapid on-off bursts of light, has the capacity for many

thousands or, theoretically, even millions of voice channels. By comparison, as pointed out in an article by Mr. John Free, 22-guage twisted-pair wire can carry 48 one-way voice channels while a coaxial cable might carry 5400 one-way channels. (39)

For most applications many fibers must be bundled together to couple them efficiently to available light sources and to provide redundancy against broken fibers. For cylindrical fibers, the closest possible bundling arrangement is hexagonal. Due to the empty spaces between fibers in a bundle, only a fraction (the so-called packing fraction) of the total bundle area is capable of accepting light for transmission. This fraction must be accounted for in designing applications requiring a minimum light transmission for detection.

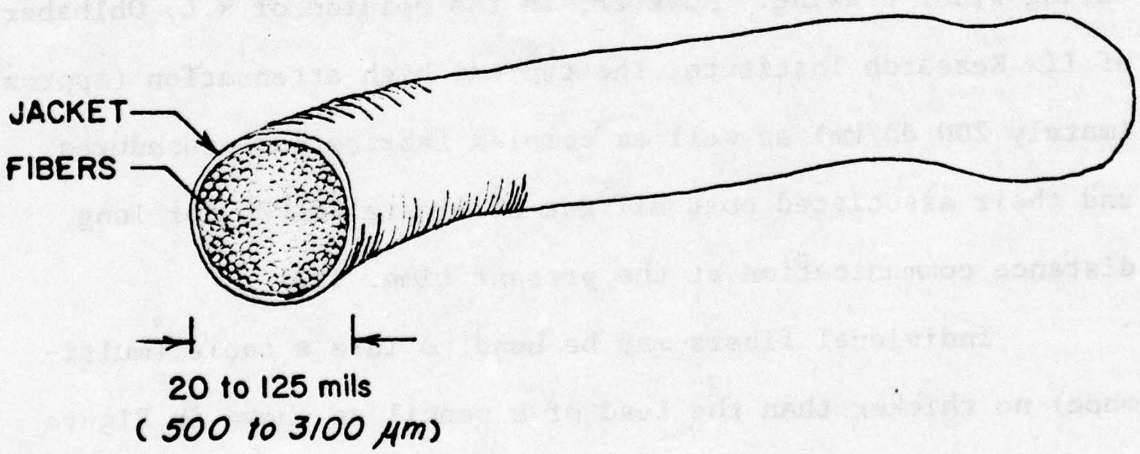


Figure 1-III-9. Fiber-optic bundle

Thirteen fiber-optic cables (multi-mode) are to be used in a point-to-point system application of the A-7 ALOFT Demonstration. The A-7 ALOFT Fiber-Optic Interface System Components Requirements call for a cable composed of 367 fibers, each fiber having a diameter of 0.00215 inches. See Appendix E. The cables are to be covered with a non-metallic jacket and shield which is non-toxic upon decomposition. Such a jacket might well be made of an improved dielectric plastic polymer compound such as "Hytrel." Extruded Hytrel tubing, made by Valtec Corporation, is completely flexible yet exhibits crush-proof characteristics. (32) Polyvinylchloride (PVC), an early candidate for protective cabling, has been eliminated as a candidate for protective cabling material because of its toxicity upon burning and its poor mechanical characteristics at high or low temperatures.

The fiber-optic cables for the A-7 ALOFT program are of the medium loss category, with a maximum optical attenuation of 590 dB/km at 910 nanometers wavelength. Cables with such attenuation characteristics would hardly be suitable for long distance communication links, but are completely suitable for relatively short distances aboard ships or aircraft. Cables with light losses of 350 dB/km means that half of the signal is lost in less than 10 meters, half of the remaining signal within the next 10 meters and so on. That's an enormous loss,

but even so, enough light emerges at the end so receivers can accurately decode the transmitted signals.

Long distance communications would require a lower loss cable (i.e., less than 20 dB/km) as well as repeaters. For example, if the one or two dB/km fibers developed by Bell and Corning Labs were used, repeaters would be spaced every 10 miles. That's better than current wire and coaxial cables, which require a repeater every few (approximately 4) miles. (39)

Current fiber-optic cables being used in the A-7 ALOFT project were supplied by Valtec Corp. Two hundred twenty-four feet of this fiber optic cable is used on a straight point-to-point system for ALOFT. It should be noted that transmission requirements in the ALOFT system configuration could have been met by 13 coaxial cables utilizing 224 feet of RG-316 coaxial cable -- but only at the expense of increased EMI/RFI susceptibility and with a slight increase in weight. (32)

3. Connectors/Couplers

a. Connectors

With any fiber-optic system there is always the problem of connecting the fiber-optic cable at either end to a light source and a data receiver. The fiber surface at either end must be rigidly held in position. The ends are polished and anti-reflection coatings are sometimes added in order to reduce attenuation. In the case of the connector at the source

end, it must be positioned such that a majority of the light from the source falls within the acceptance angle of the cable. Figure 1-III-10 In the case of detector coupling, the detector surface must be large enough to collect the spreading output light.

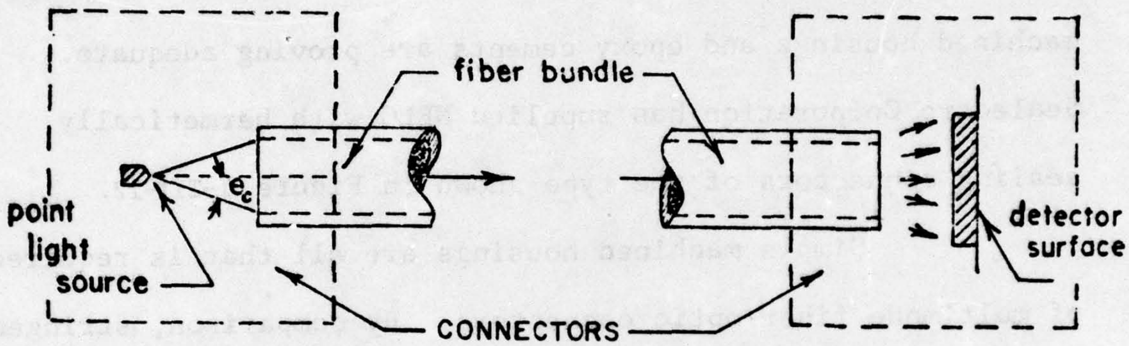


Figure 1-III-10. Multimode cable connectors

A single mode fiber, offering bandwidths up to 10^{11} Hertz, requires critical source alignment with a laser source because of its small size and small numerical aperture. Numerical aperture, NA, is defined as a measure of the light gathering capacity of the fiber:

$$NA = n_o \sin \theta_c$$

where n_o is the refractive index of the material outside the fiber and θ_c is the incident angle of the light ray.

Multimode fibers offering a bandwidth of 10^8 Hertz can be very easily coupled to multimode emitters (e.g., Light Emitting Diodes), which operate at low power and are more

efficient. They are also less expensive than a laser source. Low power operation and efficiency are intrinsic properties of LEDs -- not causes for the lower costs. The basic problem of LED-to-fiber and fiber-to-detector couplers is to maintain the proper geometry for efficient coupling. Extremely close tolerances other than concentricity are not required. Simple machined housings and epoxy cements are proving adequate. Sealectro Corporation has supplied NELC with hermetically sealing connectors of the type shown in Figure 1-III-12.

Simple machined housings are all that is required of multimode fiber-optic connectors. By comparison, stringent capacitive and inductive design requirements of electrical connectors cause housings to be more complicated. Often, parts must be gold-plated in order to satisfy these design requirements.

The problem is not simple when considering multichannel connectors. ITT-Cannon Corporation had to tackle that problem in order to design and build a 13-channel bulkhead connector for IBM to mount in the wall of the A-7 computer. Five prototypes were sold to IBM. One was delivered to NELC. The development of this connector is undoubtedly of importance, as explained by Mr. Anderson of Galileo Corp. when he says, "The development of this connector could be among the most important developments of the entire program (ALOFT Demonstration)." (39)

Little information is available on single fiber connectors. Alignment of the microscopic size core of a fiber with a source or detector surface can be critical. Present methods normally involve imbedding fibers in a substrate material or using epoxy cement as a binding agent to hold the fiber in alignment. The Deutsch Company developed a mechanical single mode connector for Corning in mid-1975, but further information was not available to the authors.

One of the biggest problems of interconnecting fiber optics involves the question of just where to make the connections. Some feel that the LED-fiber interface is the most obvious interconnection point while others feel that the critical nature of the optical interface will prevent making the connection at that point. NELC has considered three basic approaches to the problem. Figure 1-III-13. They have decided that for the present, the optical interface has several advantages over other proposed fiber-optic interface methods:

(1) Elimination of contact discontinuity at the "break point" because of the optical coupling instead of electrical contact. This eliminates such connector problems such as oxidized contacts, mechanical reliability (bent pints), etc.

(2) Throw-away modularity. The electronic circuitry, LEDs, etc., could be replaced if either failure occurs or technology advances necessitate updates.

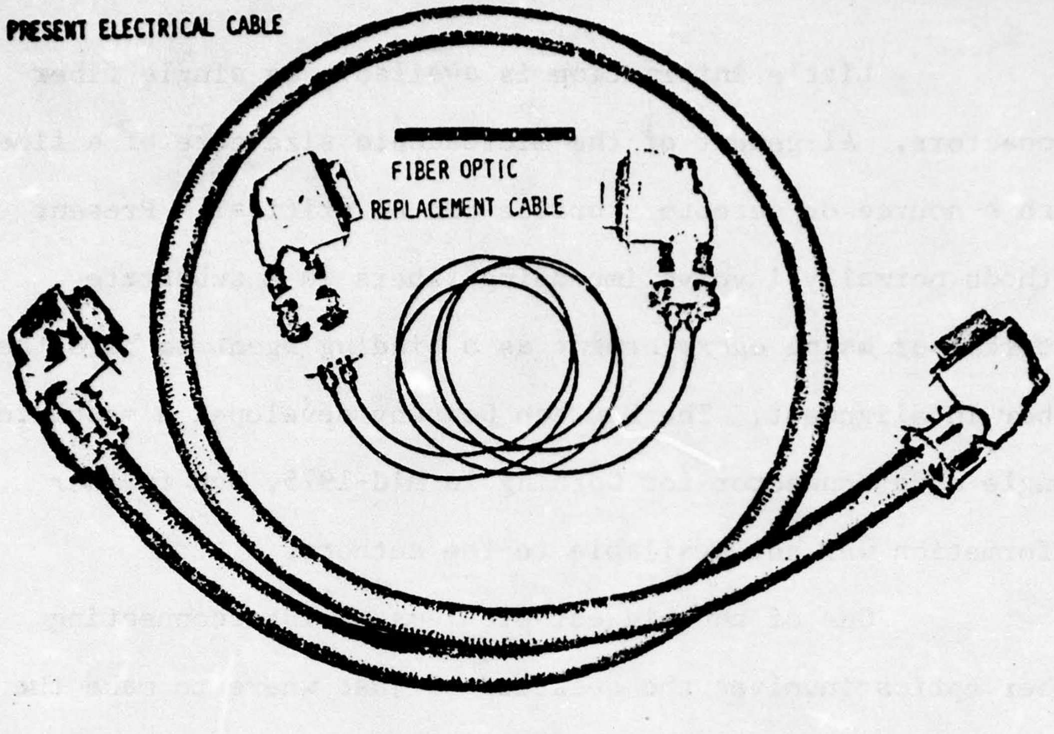
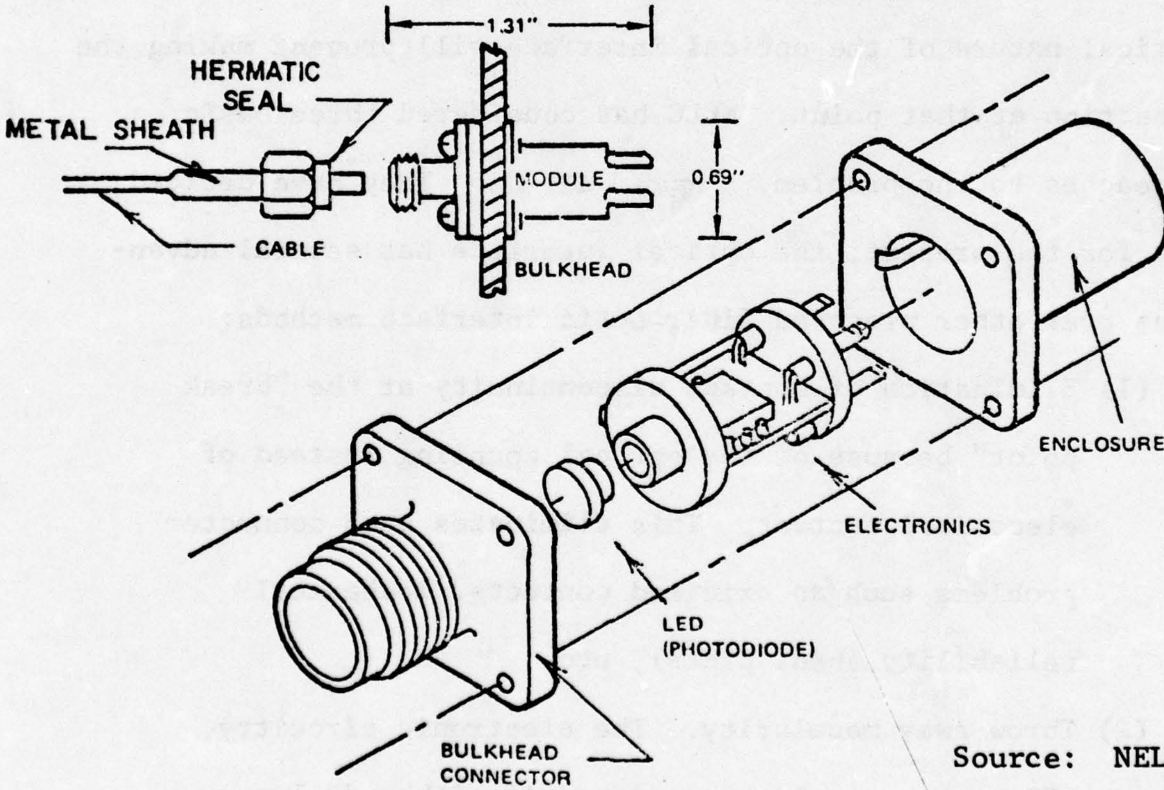


Figure 1-III-11 Typical fiber-optic link replacement.



Source: NELC

Figure 1-III-12 Standard package -- fiber-optic module

NELC 404-137 SAN DIEGO

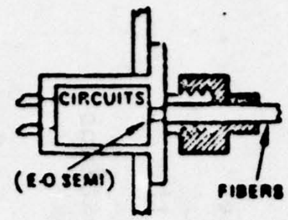
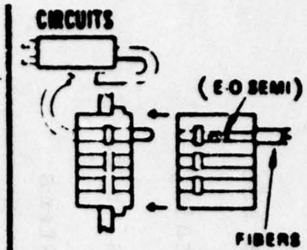
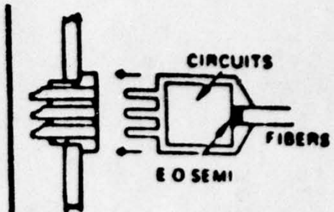
BASIC APPROACHES →	 A. OPTICAL INTERFACE	 B. ELECTRICAL INTERFACE–1	 C. ELECTRICAL INTERFACE–2
USES EXISTING OR MODIFIED ELECTRONIC CONNECTOR HARDWARE	YES, MODIFIED (BOTH)	YES, MODIFIED (HALF)	YES, MODIFIED (HALF)
ELECTRICAL PIN CONTACT DISCONTINUITY PROBLEMS ELIMINATED	YES	NO	NO
FIELD TERMINATION OF CABLE ASSEMBLIES	YES	YES	NO
EMI EMP AT CIRCUIT/E–O SEMICONDUCTOR INTERFACE	YES	NO	YES
FACTORY OPTIMIZED CIRCUIT/E–O SEMI. COMPATIBILITY	YES	NO	YES
THROW AWAY MODULARITY	YES	YES	NO
CIRCUITS AND E O SEMI. IN SAME ENVIRONMENT TRACKING TEMP	YES	NO	YES
SYSTEM LEVEL DEVICE NO CIRCUIT DESIGN REQUIRED	YES	NO	YES
OPTIMUM HEAT DISSIPATION TO BULKHEAD MOUNTING	YES	NO	NO
MIL STD 461 & MIL STD 462 QUALIFIED	YES	NO	NO
IMMUNITY TO ADJACENT CHANNEL CROSSTALK	YES	NO	YES
INTERFACES DIRECTLY WITH STANDARD DIGITAL/LINEAR FORMATS	YES	NO	YES
FIBER OPTIC CABLE CONTINUITY TEST WITHOUT SPECIAL TOOLING	YES	NO	NO TEST POSSIBLE
MATES WITH FIBER OPTIC PRESSURE BULKHEAD PENETRATOR	YES	NO	NO

Figure 1-III-13 Basic approaches to interfaces

(3) Diode-circuit matching and engineering is no longer the systems designers' problem.

(4) Easy to install and replace.

b. Couplers for Data Bus Applications

The concept of the data bus is becoming increasingly evident in the design of new generation aircraft. A data bus system is potentially less expensive to install and maintain, lighter in weight and smaller in size, more reliable, easier to modify and expand, and less vulnerable to damage than systems based on point-to-point links.

If fiber optics are to be considered as viable replacements for electrical lines in data bus systems of the future, properly designed couplers, junctions, and terminations must be perfected.

Successful laboratory models of both single-access Trunk Couplers (T-couplers) and multi-access (star) couplers have been tested at NELC. It was concluded that star couplers make it possible to implement a data bus with a large number of terminals without a repeater. If a system using "T" access couplers is used, a repeater is necessary if there are more than ten terminals. It was concluded that the information flow requirements of a modern military aircraft can be met using either access couplers or star couplers. (93) If the number of

terminals is large, resulting in unacceptable attenuation levels, a repeater would be required in an access coupler system.

4. Light Sources/Signal Drivers

Various types of light sources can be coupled to fiber optics for useful purposes. For instance, typical tungsten filament lamps, bulbs and other common light sources are used in connection with fiber optics in market areas which include TV, stereo and appliance illumination, gas and electric burner pilot light indication, dashboard and cockpit instrumentation lighting, medical endoscopes, etc., and monitoring of remote light sources. However, for communication purposes, only the semiconductor laser and the light emitting diode appear attractive for interconnections on aircraft and spacecraft.

The signal driver for the A-7 ALOFT Project utilizes a discrete circuit driver-amplifier with LEDs, resistors, capacitors, and integrated circuit amplifiers all mounted on a circuit board. The much more desired hybrid fiber-optic driver is yet to be delivered to NELC by an impending contract. It will be delivered at too late a date for consideration in the ALOFT Project.

a. Light Emitting Diodes (LEDs)

Light Emitting Diodes are the most widely used light source today. They are used in the A-7 ALOFT Project because

of their availability and their operating characteristics which readily satisfy important characteristics which must be considered in the selection of a light source for fiber-optic systems. These characteristics are: (2)

(1) Wavelength of light output within frequency spectrum detectable by available photo detectors.

(2) Size of light source emitting region is compatible with the multi-fiber cables.

(3) The power requirement is compatible with the aircraft electrical system ($\leq$ 28vdc). Specifically, it is TTL compatible ($\angle$ 5vdc).

(4) Coupling efficiency allows light emission such that output power is radiated with an angle, Θ, for efficient coupling to a fiber-optic cable. In addition, power efficiency of LEDs provides sufficient light to overcome coupling and cable loss and does not require external cooling.

(5) The response time of LEDs is fast enough so as not to distort high rate (15-20 Megabits) signals.

(6) LEDs, which have a much longer lifetime than laser diodes, are believed capable of operational lifetimes measured in hundreds to thousands of continuous hours at 25°C.

A light emitting diode is a semiconductor chip which contains a P-N junction, mounted in a header and encapsulated beneath a transparent window. This semiconductor basically converts an electrical signal from the aircraft electrical system into an infrared ($\sim$ 9000 Å) light for transmission through a fiber-optic cable. Light emitting diodes make use of a P-N junction for light generation in much the same way as injection lasers except that no optical resonator is used to control the gain in the device.

The intensity of light output from the LEDs is proportional to the current through it. Thus, the amplifier output current controls the light intensity. Since LEDs operate at much lower current densities and optical densities than semiconductor lasers, they do not suffer unsolvable degradation and reliability problems.

The amount of information an LED can transmit is limited by its frequency response -- how fast it can be turned on and off. At this time LEDs can be modulated up to a few hundred megahertz. This is suitable for some 50,000 voice channels, which require 4000 Hz of bandwidth each, or some 30 TV channels, each requiring six MHz of bandwidth. (39)

Driver requirements for LEDs are much less severe than for semiconductor lasers. In general, the voltages on the LEDs and semiconductor lasers are approximately 2 to 3

volts. For some applications, LEDs with one TTL output, can be driven with currents of approximately 20 mA at frequencies not exceeding 30 MHz. For these device applications, transistor-transistor-logic (TTL) circuits are convenient drive circuits, whether they are off-the-shelf items or custom integrated circuits.(1) In summary, electronic drive circuits for LEDs and semiconductor lasers are readily available for requirements at least to 50 MHz.

b. Semiconductor Lasers

Of all the laser sources, the semiconductor laser holds the most promise for high data rate fiber-optic systems. Their characteristics of small size, simplicity of design, ease of high frequency modulation, and relative high power conversion efficiency make them ideal as light sources.(1)

A laser diode can be as small as a speck, barely visible to the eye. They are capable of emitting very narrow spectral outputs (spectral widths of less than a nanometer are possible), which makes them ideal for the microscopic core of a single mode fiber. Lasers can be pulsed in the gigahertz range, and thus can transmit far more information than an LED.

Several companies are now working on laser injection diodes. Corning Glass has developed fibers which have a square cross section which can be bonded side by side into a flat ribbon. This ribbon can then be bonded to a laser injection diode as shown in Figure 1-III-14. (1)

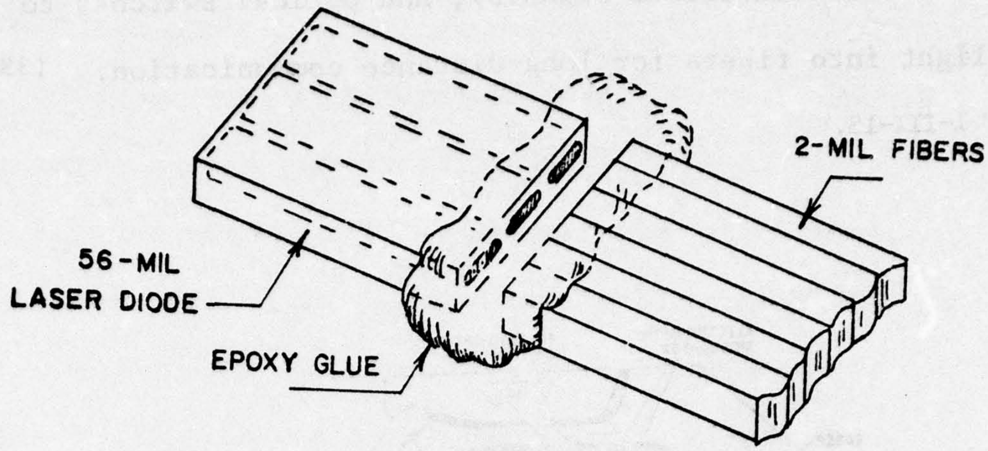


Figure 1-III-14 Laser injection diode bonded to fibers

A few of the companies involved with laser injection diodes are: Sperry Rand, IBM, Bell Labs, and Texas Instruments. Bell Labs revealed in mid-1975 that they have been able to integrate familiar optical components such as lenses and prisms on special substrates. Bell has also integrated all the components needed to generate, modulate, deflect, and detect optical signals onto a single chip. (39) Most optical engineers feel that the greatest potential of laser diodes will be realized when integrated optical circuits (IOCs) are as common as integrated circuits (ICs) now used in calculators and other electronic equipment. Instead of transistors on a button size surface, IOCs will have microscopic lasers, modulators

(to put signals on a laser beam), photodetectors (to convert light back into electronic signals), and optical switches to route light into fibers for long distance communication. (39) Figure 1-III-15.

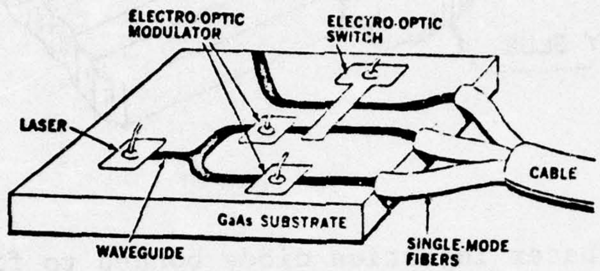


Figure 1-III-15. Optical circuit on a chip as envisioned by Texas Instruments. Bell Labs recently formed such components on a single chip.

An important consideration of semiconductor lasers is that they can be modulated at extremely high rates. The modulation rate is intrinsically limited only by minority carrier lifetime in the semiconductor crystal. Carrier lifetime has been determined to be less that 10^{-10} seconds, which implies a modulation rate capability of ten gigahertz. (52) The bandwidth available is phenomenally higher. Light wavelengths involved translate into some 500,000 gigahertz -- enough bandwidth, theoretically to carry some 83 million TV signals simultaneously. The limitation in signal carrying capacity is how fast light sources can be modulated. (39)

5. Signal Receivers/Detectors

For the purpose of this study, detectors are analogous to a receiver. Optical signals are required to be demodulated through use of a photodetector which is sensitive to low light signal levels at the incident wavelength. A photodetector is a device in which the voltage or current output depends on the intensity of light falling on the light sensitive region of the device. The incident photons cause hole electron pair formation in the junction region which causes current to flow through the junction to an external load resistor which causes a voltage drop proportionate to the incident photons striking the detector junction. (73)

Detector requirements for fiber-optic applications are not particularly unique and much of the technology which has been developed in the past is applicable. However, some very important characteristics and requirements must be considered for fiber-optic applications: (2)

(1) Wavelength of transmitted light must be within the region of wavelength sensitivity of the receiver.

(2) The size of the light sensitive region of the receiver must be compatible with the particular fiber-optic cable for efficient light energy coupling.

(3) The electrical power system of the aircraft must be compatible with power required by the detector.

(4) Sensitivity must be such that incident light rays from the original signal source can be demodulated with a minimum amount of distortion.

(5) Mechanical constraints, such as simplicity, light weight, ruggedness, temperature coefficient, etc., must be met.

These conditions can be met by using commercially available positive intrinsic-negative (PIN) diodes with commercially available amplifiers. PIN diodes are quite satisfactory for short run applications such as the ALOFT system, but the avalanche photodiode is preferred in the long run where greater sensitivity is required in the bandwidth regime out to 15 megacycles per second. This improvement is obtained at the cost of more complex biasing networks and less proven reliability. (31)

D. SYSTEM DESCRIPTION OF FIBER OPTICS AS EMPLOYED IN THE A-7 ALOFT DEMONSTRATION

1. System Description

The original A-7 data communication system as utilized by the A-7 Navigation Weapons Delivery System (NWDS) is a point-to-point system which uses twisted pair wire and coaxial cable

interfaces in the Navy and Air Force versions of the operational aircraft. Certain portions of that system, as shown in Figure 1, Appendix C, have been converted to a multiplexed fiber-optic interface by the A-7 ALOFT Project. The original wiring will be left in the aircraft and will be reconnected for use upon completion of the A-7 ALOFT Demonstration. Since no change in the input/output (I/O) design of the avionics (other than the computer) was authorized, the fiber-optic interface with the peripheral avionics units has been achieved through external adapter units which contain all electro-optic and multiplexing/demultiplexing (MUX/DEMUX) circuitry and which are connected to the avionics with wire adapter cables.

The data communications encompassed by that portion of the system shown in Figure 1, Appendix C, which has been converted to a multiplexed fiber-optic interface by the ALOFT Project, consists of 123 signals. After electronic multiplexing, these signals are transmitted in the ALOFT Project over only 13 point-to-point fiber-optic cables, as opposed to approximately 300 wires which were required to transmit these same signals in the original A-7 system configuration. The fiber-optic configuration of the system is shown in Figure 2, Appendix C. Figure 3, Appendix C, shows only the electro-optic, MUX/DEMUX and fiber-optic portion of Figure 2, Appendix C, that is being

installed in the ALOFT Project. The computer shown in Figures 2 and 3, Appendix C, is an internally modified version of the original A-7 computer containing all necessary electronic multiplexing/demultiplexing circuitry to reduce the interface density required for the transmission of the signals to 13 channels of information flow at a maximum of a 10-megabit data rate. (32)

IV. AN APPROACH FOR A COST-EFFECTIVENESS STUDY OF AVIONICS DATA LINK ALTERNATIVES

A. GENERAL

Engineering research and development of fiber-optic cabling in aircraft has reached the stage where it is appropriate to begin assessing the cost and effectiveness of this emerging technology as a possible replacement for coaxial and twisted pair wire cabling in avionics data transmission wiring suites. The general approach for the analysis, as required by SECNAV INSTRUCTION 7000.14 A, and as desired by NAVAL ELECTRONICS LABORATORY CENTER, SAN DIEGO, is an economic analysis. An outline of this process is provided in Figure 1-IV-1. The basic format of an economic analysis involves the determination of the cost and effectiveness of each of the competing alternatives, i.e., fiber optics and conventional wiring. Once this task is accomplished, the decision maker should be better able to make a rational choice between the competing systems.

The framework for cost and effectiveness analyses for any system usually follows one of two conceptual approaches:

(1) Fixed Effectiveness Approach - For a specified level of effectiveness to be attained in the

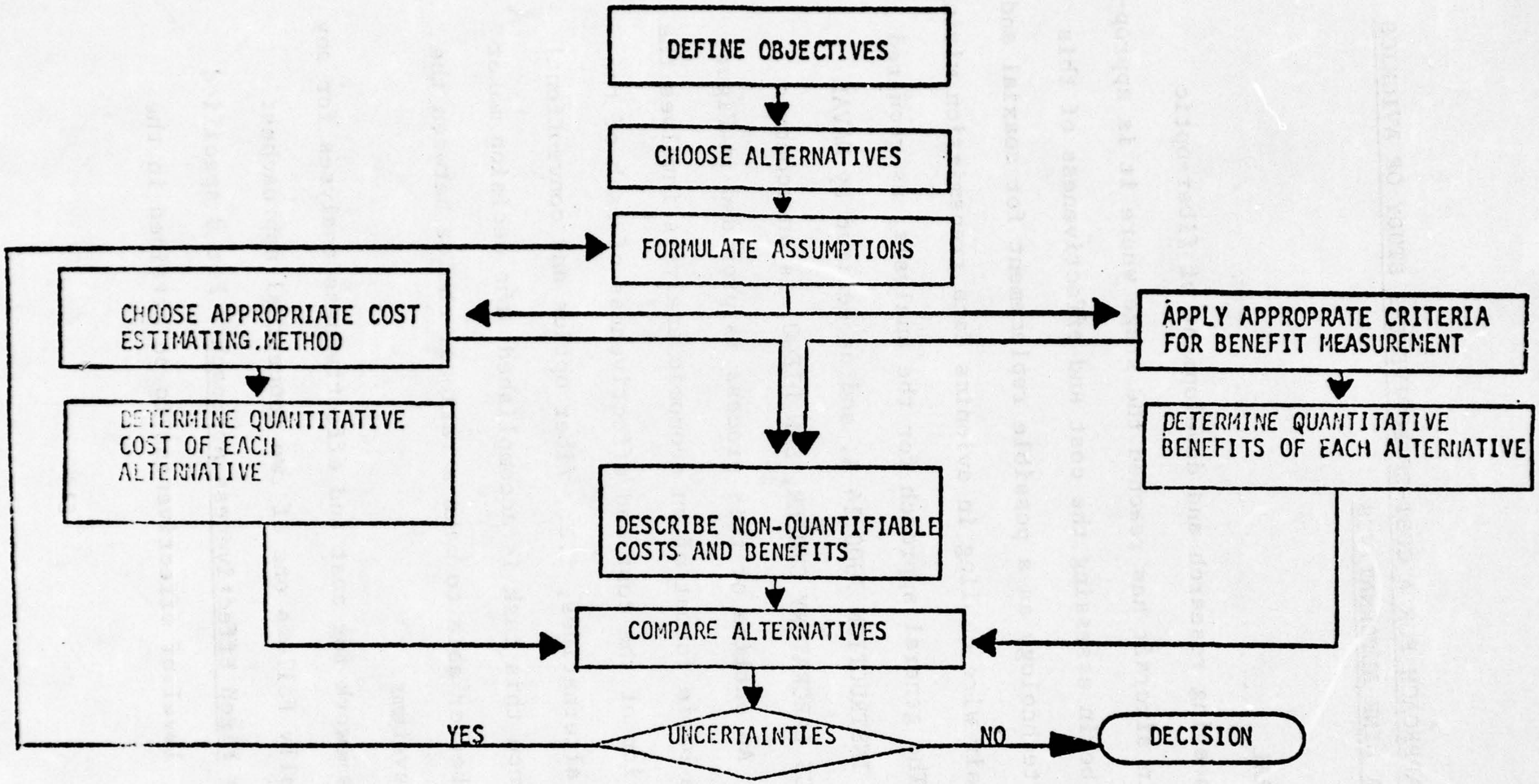


Figure 1-IV-1 Economic analysis process

accomplishment of some given objective, the analysis attempts to determine that alternative which is likely to achieve the specified level of effectiveness at the lowest economic cost.

(2) <u>Fixed Resource Expenditure Approach</u> - For a specified cost level to be used in the attainment of some given objective, the analysis attempts to determine that alternative which is likely to produce the highest effectiveness. (38)

While either approach is possible, the fixed effectiveness approach might be more appropriate for the alternatives being considered in the case of data link systems. The fixed resource expenditure approach would apply more to an entire weapons system purchase, such as fighter aircraft, where a resource constraint can probably be more easily stated. Further, fixing resource levels would require extensive and detailed cost data at a subsystem level which is, in most cases, not available. Therefore, the authors feel it is appropriate to fix effectiveness at a desired level for both competing systems while minimizing costs.

A level of effectiveness as referred to in most cost-effectiveness publications usually relates to a single measure of effectiveness and the unit values that may be achieved for a given unit cost. In fiber optics there exists a myriad of

effectiveness measures that must be evaluated. A level of effectiveness for fiber optics would therefore consist of the quantification of all the MOEs.

Each specified level of effectiveness will have a cost associated with it resulting in the well known cost-effectiveness curve. Figures 1-IV-2 and 1-IV-3 serve as examples. Figure 1-IV-2 illustrates the case where one alternative, B, exhibits "dominance" over its competitor, A, in every case. When dominance occurs, there is little need to proceed further with an analysis. Common sense would clearly indicate a choice of the dominant alternative. Figure 1-IV-3 illustrates a case where alternative A exhibits dominance over alternative B over the range of the first four levels of effectiveness. However, alternative B is dominant at effectiveness level five and above. This could be of considerable significance if, for instance, weapons systems designers and decision makers insisted on acquiring a system capable of operating at effectiveness level five or above. Both alternatives could reach level five but at considerable cost differences. The obvious choice in this case is to choose alternative A for the first four levels of effectiveness and to choose alternative B if effectiveness level five is desired.

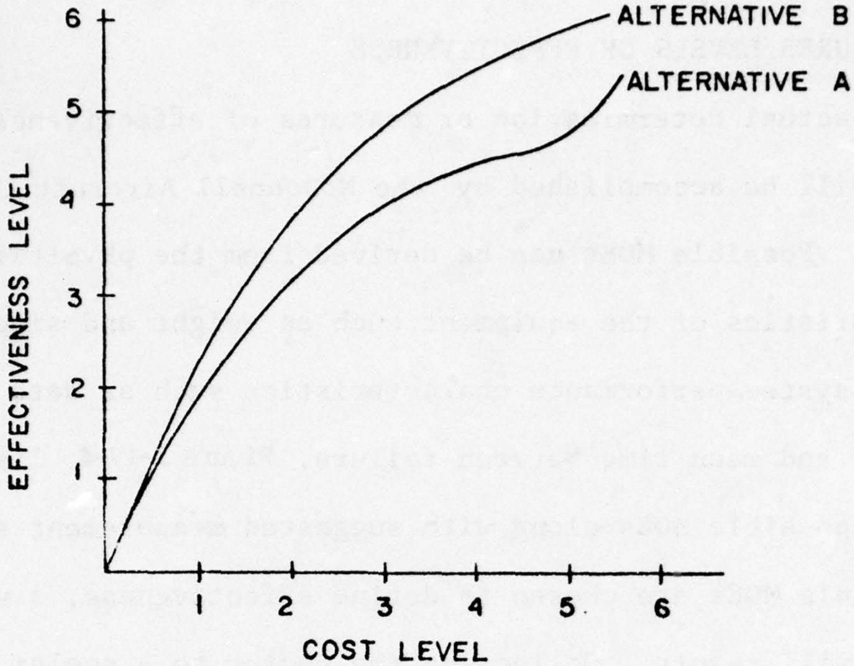


Figure I-IV-2 Hypothetical cost effectiveness curves displaying dominance.

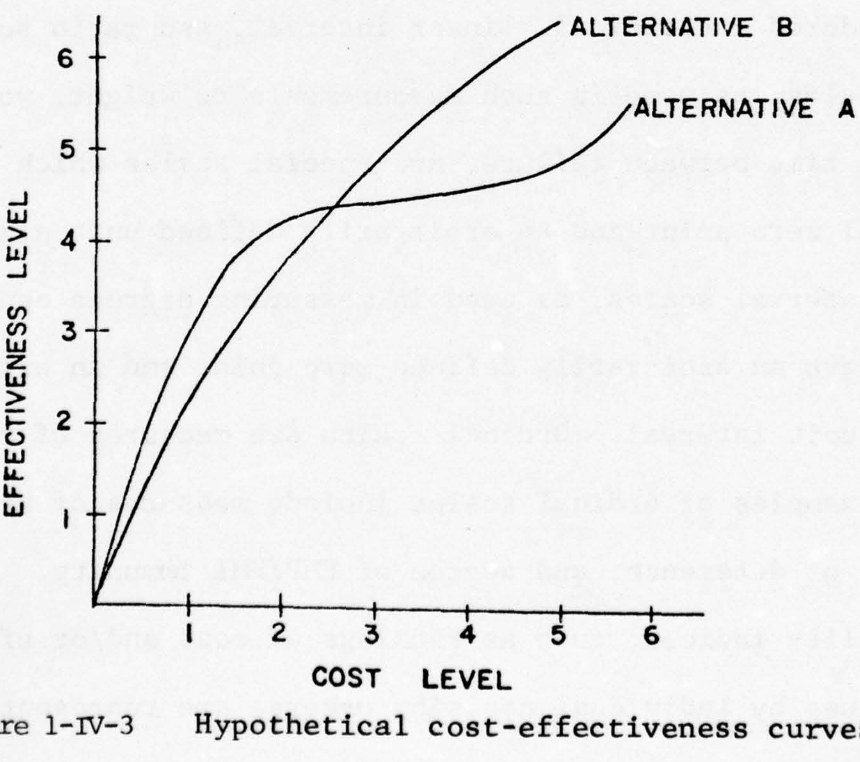


Figure 1-IV-3 Hypothetical cost-effectiveness curves

B. MEASURES/LEVELS OF EFFECTIVENESS

The actual determination of measures of effectiveness (MOEs) will be accomplished by the McDonnell Aircraft Company (MCAIR). Possible MOEs can be derived from the physical characteristics of the equipment such as weight and size as well as system performance characteristics such as data rate capacity and mean time between failure. Figure 1-IV-4 lists several possible MOEs along with suggested measurement scales. If multiple MOEs are chosen to define effectiveness, a vector of MOEs will result. Collapsing the vector to a scalar introduces two problems. First, a method must be determined to combine MOEs measured by different scales. Typical scales to be considered are ordinal, linear interval, and ratio scales. Ratio scales, as used in such measurements as weight, volume, and mean time between failure, are special scales which have a natural zero point and an arbitrarily defined unit size. Linear interval scales, as used in measuring degrees centigrade, have an arbitrarily defined zero point and an artibrarily defined unit interval. Ordinal scales are measures of relativeness. Examples of ordinal scales include measures of hardness, measures of deterence, and degree of EMP/EMI immunity. In fact, many utility indices, such as rankings of cost and/or effectiveness issues by individual decision makers, are representable by ordinal scales. The second problem concerns the relative

weights that must be assigned to the components (MOEs) of the effectiveness vector. Such assignments are necessarily subjective because they depend totally on the judgment of the individual making the weighting assignments. Both problems, combining MOEs measured by different scales and assigning weights to the MOEs, can be eliminated if the fixed effectiveness approach is utilized since the competing systems will have the same effectiveness level.

When the relevant MOEs are determined, actual magnitudes can be assigned. The right hand side of Figure 1-IV-4 illustrates five hypothetical assignments. The assignments represent five different levels of effectiveness that may be required or desired of the competing systems. Once the costs are determined for the competing systems at the different levels of effectiveness, the cost-effectiveness curves as illustrated in Figures 1-IV-2 and 1-IV-3 can be constructed. These curves then provide the decision maker with the necessary information to make a rational decision.

C. COST ANALYSIS

1. Life Cycle Costing

The costing methods as required by NELC are being done in terms of the life cycle costs (LCC) for both a coaxial and fiber-optic aircraft avionics system configuration as represented in the A-7 ALOFT Demonstration.

HYPOTHETICAL MEASURES OF EFFECTIVENESS (MOEs)	(MEASUREMENT UNIT)	(SCALE)	LEVELS OF EFFECTIVENESS (1 = Low, 5 = High) 1	2	3	4	5
Mean Time Between Failure	(Flight hrs)	R	1	5	10	20	20
Mean Time to Repair	(Maint. hrs)	R	5	5	3	2	1
Weight per avionics system	(Pounds)	R	125	125	100	50	25
Size, or volume, per avionics system	(Cubic feet)	R	20	20	10	5	3
Sparks, grounding, and fire hazard immunity	(Yes/No)	O	NO	NO	NO	NO	YES
Cable redundancy	(# of routes)	I	1	1	2	2	3+
EMP/EMI immunity	(Yes/No)	O	NO	NO	NO	NO	YES
Signal bandwidth	(Megahertz)	I	50	75	100	150	200
Signal attenuation	(dB/km)	R	300	300	200	100	20
Power consumption	(Watts)	I	50	50	20	10	5
Vibration tolerance (Mean Cycles to Failure)	(Cycles)	I	10,000	15,000	20,000	30,000	30,000
Heat resistance (Highest operating temp.)	(Degrees C)	I	50	60	70	80	80
Cold resistance (Lowest operating temp.)	(Degrees C)	I	0	-10	-20	-30	-30
Twist tolerance (Mean Twists to Failure)	(Twists per Foot)	R	3	4	5	7	7

Figure 1-IV-4 Measures of effectiveness (hypothetical)

The task of estimating life cycle costs for wire interconnect components (coax/twisted pair, etc.)is being accomplished by MCAIR. Two NPS students have developed a life cycle cost model which is being used by NELC to prepare cost estimates for the figer-optic alternative. (See Volume Two of this report).

Life cycle cost estimates used for making a particular decision, such as data link selection, need not be the total life cycle costs for the system. Costs which would be the same for each alternative and costs incurred prior to the decision (sunk costs) should be excluded. Sunk costs are those resources (money, etc.) which have been expended and which cannot be recovered. They are therefore irrelevant and should not influence future decisions. However, any assets created as a result of such expenditures are relevant.

Care must be used in the choice of costs to be excluded lest their omission improperly influence the decisions to be made. For example, consider one aspect of the present cost analysis. It has been decided to exclude the electronic equipment (including the MUX/DEMUX components) not incidental to drivers, connectors, cables, and receivers because those equipment costs appear to be common to both data link alternatives. This restricts the analysis to the trade-off between the costs

and reliability of competing alternatives. One might consider whether or not the costs of the MUX/DEMUX units are really common to both alternatives. For instance, electronics manufacturers might find it more costly to modify their standard electronic units to accomodate fiber-optic components (such as multi-channel bulkhead connectors, etc.) than to use off-the-shelf units for conventional wiring/cabling. Thus the assumption on which the MUX/DEMUX equipment costs were excluded would prove to be invalid.

2. Cost Data Collection Effort

Cost data collection, one of the first steps of a cost analysis, provides specific costs for elements of the system on which a simple price tag can be placed, or for which a nominal extension can be made of costs experienced in similar programs. A literature search and telephone survey by the authors confirm the generally known fact that cost data for

elements of a fiber-optic data link system, other than pre-production prototype costs, are not generally available. It is true that costs (i.e., price to the user) of fiber-optic systems components such as cables, connectors, receivers and drivers, can be obtained -- but these prices usually reflect contract prices on one-time bids. The prices paid today are not indicative of prices that will be paid tomorrow for components produced on either a one-time contract basis or a full production mode basis.

Most of the available cost information has been obtained from NELC sources (APPENDICES E, F, and G). The cost information provided by NELC has been verified by the authors as being representative of the wide range of costs generally associated with components of an emerging technology.

One of the principle reasons for wide cost dispersions is the lack of standardization of component parts. For instance, if one needed a fiber-optic system to perform a particular function, and if this person was to approach several fiber-optic manufacturers for bids, he would immediately be faced with the problem of non-comparability of different manufacturers' components. The customer would be faced with the problem of defining perhaps dozens of his own desired design requirements: single mode, multimode (how many fibers?), desired cabling (will it be toxic upon decomposition?), packing fraction, numerical aperture,

index of refraction, attenuation limits, flexibility, diameter, per cent breakage tolerance, etc. After defining his needs, he should not be surprised to learn that no two manufacturers have similar cables to meet his needs, nor are standardized couplers, drivers and receivers available. The customer would find, however, that a fiber-optic system could be designed and built to meet his needs -- but at considerably higher cost than he might have first anticipated.

A few examples will be given to illustrate the uncertainties involved in gathering data for component costs.

Although module driver/receiver units have cost in the range of hundreds of dollars, Mr. J. R. Biard, of Spectronics, Inc., indicates that it would not be unreasonable to expect to see prices for driver/receiver modules drop to a \$10 - \$12 range when in full production. (9)

Galileo's 400 dB/km multimode cable was selling for \$2.50/ft in 1974. It was selling for \$0.75/ft in August 1975. Mr. Rodney Anderson, of Galileo, indicates that he could reduce that price by half, or more, with purchase quantities greater than 100,000 feet. He feels that his 35 mil fiber-optic bundle could compete with micro-coax cable on a cost-per-foot basis but, as yet, there is not enough consumer demand to generate cost savings which in turn, with competition, would lead to the lowering of prices below \$0.75/ft. (4)

Mr. Robert Freiberger, of Corning Glass Works, states that his company "has been in a full production mode for fiber-optic bundles for the past 7-8 years." (40) In 1974, Corning's 19-mode 30 dB/km cable was selling for $17.37/ft when sold in less than 5,000 meter quantities. Corning reduced attenuation from 30 dB/km to 20 dB/km at the 820 nm wavelength while reducing the price by 36 percent in 1975. The price in mid-1975 was $10.97/ft for purchase orders of less than 5,000 meters and $5.56/ft for purchases greater than 5,000 meters. Corning's current emphasis, however, is on single-mode cables rather than multimode bundles. Corning's most important fiber-optic product is a single-mode low-loss ($<$ 6dB/km) cable called CORGUIDE. CORGUIDE presently sells for $13.50 per meter or about $4.11 per foot. This equates to about $.59 per foot for each low-loss fiber as there are seven individual fibers in CORGUIDE.

"Corning is putting millions of dollars yearly into fiber optics research and development," states Mr. Freiberger. One of their recent developments, in conjunction with the Deutsch Co., has been the development of a hopefully reliable mechanical fiber-to-fiber connector for single-mode cables. Corning's efforts are aimed directly at capturing a major portion of the potentially large market that will result from fiber optics utilization by American Telephone and Telegraph Co. in the 1980's. Mr. Freiberger sees little chance of lowering prices

for a military market in fiber optics in the near future as it would take a potential $100 million per year market to induce Corning to drastically lower prices or alter production. "In a full production mode, with markets above $100 million per year," Mr. Freiberger states, "it would not be unreasonable to look for costs of CORGUIDE to drop from $4.11 per foot to about $.10 per foot. This equates to a little over 1¢ per foot for low-loss fiber." Mr. Freiberger makes the interesting prediction that Corning's costs of production for low-loss fibers will continue to decrease. As this occurs, the currently less expensive medium-loss multimode fiber-optic bundle (with hundreds of individual fibers in each bundle) will become more costly to produce than low-loss cables such as CORGUIDE. (40)

Costs for connectors are not, in general, as uncertain as other fiber-optic component costs. The exception would be the 13-channel bulkhead connector developed by ITT Cannon Co. for NELC/IBM at a price of $500 each for a total of six connectors. (77) It has subsequently been reported to the authors that ITT Cannon Co. has sold this same connector to a leading aircraft manufacturing company at a price of $50.00 each. (32)

Single channel connector costs are nominally low at $2.50 - $3.50 each. This lower price is generally attributed to the fact that mechanical connector technology and manufacture is not new. Connector manufacturing companies already have the

production base necessary to produce fiber-optic connectors for multimode cables.

According to Mr. Biard of Spectronics, Inc., the development of integrated optical circuits today is in the same relative position that integrated circuits were in in 1958 -- a full three to four years before a firm production base was established. (9) Mr. Biard makes one clear distinction, however; in 1958, the electronics industry was receiving substantial financial assistance from the U.S. Air Force for the specific purpose of perfecting and developing integrated circuits. The electronics industry today is <u>not</u> receiving the funds and support necessary for the same pace of development. Mr. Biard feels that unless more government funds are made available for the purpose of IOC research and development, integrated optical circuit growth and development will be much slower than the previous growth of integrated circuits. Ample statistical data exist in the field of integrated circuits such that meaningful cost analogies, for the purpose of predicting costs, could be utilized once a cost data base has been established for IOCs.

Statistical data could not be correlated because, in many cases, there was no common ground for comparison. It was generally observed, however, that costs are definitely in a downward trend. The rate of price decline will continue to depend on demand and technological development trends but it would not be unreasonable to expect prototype costs of some components to be reduced by a factor of 10 within the next few years.

D. COMBINING COST AND EFFECTIVENESS

1. Ordering Uncertainties Through Scenarios

Technological forecasting is by definition, an area fraught with uncertainty. It has been seen in earlier discussions in this work that technological developments in the field of fiber optics have many uncertainties -- all of which should be considered by a decision maker. For example, before a decision maker can make a final choice of future avionics data link systems, he must face the overall questions of how, when and why to implement any given system. In the case of fiber optics, he must concern himself with the future technical composition of the fiber-optic data link. One most certainly would not choose the one-time application of discrete circuitry used in the A-7 ALOFT Demonstration. In fact, technological developments are accruing so rapidly, he might not choose any

of the now existing components. Listed below are several of the important uncertainties about which a decision maker must be concerned:

(1) Technological levels of sophistication desired for fiber optics: multimode or single mode fiber-optic cables; low-, medium-, or high-loss cables; point-to-point or data bus systems; data capability rates of kilo-, mega-, or giga-bits per second; discrete, modular, or integrated optical circuits; rugged strength or small size, light weight cables; redundant or single path data links; LED drivers or laser injection diode drivers; standardization of components to meet military specifications; low-loss T- and Star couplers; reliable single mode mechanical connectors; bandwidth -- How much is "enough," etc.?

(2) Avionics systems design requirements: Will military decision makers insist on higher EMP/EMI immunity standards for future avionics systems; Will data transfer rate requirements for complex computerized avionics systems be increased beyond present data link capacity; Will wiring-path redundancy be required for increased reliability/survivability; Should avionics systems be utilized in any one type of

military aircraft -- or all types of military aircraft; Are fiber-optic data links desirable for all weapons systems; etc.?

(3) Timing: When will each of the technological developments mentioned in (1) above be off-the-shelf available; When will technological advances level-off enough to preclude an existing generation of fiber-optic components from approaching either apparent or perceived obsolescence as happened in the case of 1st, 2nd, and 3rd generation computers; When will there be sufficient market potential to induce fiber-optic producers to mass produce components; Does even the strongest possibility of a military "go-ahead" in this area offer enough incentive for industry to establish a production base for mass production; What market potential (measured in millions of dollars and/or millions of feet of cable) will be sufficient inducement to industry; When will military design requirements force military decision makers to utilize fiber optics in order to meet EMP/EMI immunity requirements; When (and how much) will government sponsored R&D funds be made available to industry and/or the military for continuing research and development; When will data transfer rates greater than the limits

of coax cable be required; When will the fiber-optic data link system be technically and/or economically feasible for avionics suites; What is the earliest time frame we could expect to use fiber optics in shipboard use; etc.?

The uncertainties described above can present a confusing situation when taken together. Scenario construction often offers relief in this area by structuring uncertainties in a logical sequence of events in order to show how, starting from the present, or a base year such as the beginning of FY 1977, a future state might evolve, step by step, to a terminal date, say 1990. The purpose is not to predict the future, but to refine information on the forseeable "climate" for various fiber-optic technological advances and system utilizations. Kahn, in the introductory chapter to his study on scenario technique, emphasizes that "the scenario is particularly suited to dealing with several aspects of a problem more or less simultaneously." (57)

Through the use of a relatively extensive scenario, the analyst may be able to get a "feel" for events and for the branching points dependent upon critical choices. These branches can then be explored systematically. The authors have attempted to structure several events and branches on a representative

basis of (1) a neutral context, (2) a modestly optimistic context, and (3) a modestly pessimistic context. It should be emphasized that these are only three of an infinite number of possible scenarios. An entire study could be made on the dozens of uncertainty branch points and the resultant event trees which could develop from each.

Two of the advantages that Kahn points out in his discussions are: Scenarios are one of the most effective tools in lessening "carry-over" thinking; scenarios force one "to plunge into the unfamiliar and rapidly changing world of the present and of the future by dramatizing and illustrating the possibilities they focus on." Secondly, scenarios "force the analyst to deal with details and dynamics which he might easily avoid treating if he restricted himself to abstract considerations. Typically, no particular set of the many possible sets of details and dynamics seems specially worth treating, so none are treated, even though a detailed investigation of even a few arbitrarily chosen cases can be most helpful." (57)

The analyst should be aware that certain dangers may arise from the use of scenarios to help guide and facilitate further thinking and analysis. Specifically, the initial conjectures might be assumed erroneously to be sufficiently correct to lead to scenarios with some content of "reality." However, as Kahn remarks, "a specific estimate, conjecture, or

context, even if it is later shown to have serious defects, is often better than a deliberate blank which tends to stop thought and research."

a. Scenario I - A Neutral Context

The scenario begins in October, 1976, the beginning of the 1977 Fiscal Year -- the year that NELC has chosen for an economic analysis for fiber optics. One million feet of fiber-optic cable is produced annually. Flight testing of the A-7 fiber optics demonstration aircraft has been completed as scheduled. The results of the first Delphi questionnaire have been received and refined. These results, together with the life cycle cost model constructed by NPS and NELC, have been exercised. The results are such that it has been decided to expand the model to analyze a particular multiplexed data bus system utilizing the building block components described in NELC TD-435. (See Appendix E) By October 1977, with the expansion of the models, a trade-off analysis is performed for a data bus concept. The results of the economic analysis indicate a choice of parity between fiber optics and coaxial systems. There seems to be no question of the technical feasibility. Test results indicate that desired EMI/EMP immunity can be obtained. It is decided by military aircraft designers and decision makers to utilize multimode fiber optics with modular LED circuits on a limited number of aircraft as a pilot

application. A multiplexed multimode data bus avionics system will be designed and installed in the Navy's 16 ES3 aircraft being developed for the Tactical Airborne Surveillance Exploitation System (TASES) program. The aircraft will be built in 1981. It is decided that this will be the only multimode application. Future aircraft avionics designs will utilize single mode if the TASES avionics systems work well. These follow-on military aircraft of the mid-to-late 1980's will also utilize IOCs. By mid-1977, fiber optics are still primarily used in laboratory and test demonstrations. Demand is small. Any one of the major fiber-optic cable producers is able to produce enough high-, medium-, or low-loss fiber-optic cable in a period of only a few weeks to satisfy the market demand of the entire United States for one year. Fiber-optic cable production in 1978 totals two million feet. As of 1978, there is no standardization of components (cable size, connectors, circuits, etc). Modular type driver and receiver circuits have been produced in small quantities on contract bases for various contractors to use in laboratory applications of multimode and single mode fiber optics for the past two years. Successful demonstrations of T- and Star-couplers have encouraged the Navy to conduct further demonstrations of fiber optics feasibility. Following the "float-off" sea trials between the Rohr and Bell Cos., the prototype 2000-ton Surface Effects Ship (2KSES) is

to receive a fiber optics data bus system, utilizing multimode cables, in 1978. The data bus system utilizes prototype T-couplers and modular driver and receiver circuits. In 1978 it is decided to use fiber optics in the avionics package of the VPX (replacement aircraft for the Navy's P-3). The Navy, now convinced of the technical feasibility of fiber optics, plans to use a single mode fiber-optic data bus system in the VPX when production commences in 1983. It is apparent during the 1978-1979 time period that the military is the primary user of multimode fiber-optic cable. Cables, connectors, modular drivers, etc., have been standardized for military application, but much of this effort will be of questionable value as multi-mode applications are planned to be phased out, during a five-year period, in favor of single mode applications. Industry's efforts are concentrated on technological developments relating to single mode cables in conjunction with integrated optical circuits. The sale of multimode cables to military consumers has little financial impact on the producers. They are not dependent on a military market. The Navy and Air Force have decided against large scale retrofit programs. However, the Air Force is retrofitting one B-1 bomber in a program similar to the ALOFT Demonstration. The Air Force will utilize a single mode data bus system in the B-1 Demonstration. They will use prototype components developed by industry. By 1980, the U.S.

Army has begun to replace an initial segment of four million feet of tactical communication lines with single mode fiber-optic cable. Their plans are to replace a total of 16 million feet of 26 pair coax cable by 1985. One fiber optics producer wins the contract, but he is still not dependent on the Army for continuing profits, etc. Because fiber-optic cable is relatively simple to make, he is able to stay far ahead of the Army's need through use of his pilot plant facility, and in fact can produce the entire 16 million feet of cable with only a few months of productive effort. Industry is still concentrating on the single mode market. Production in 1980 totals three million feet of fiber-optic cable. In 1980, the United States is experiencing a rate of inflation of 6-7 percent per year, but certain materials are considered "strategic" and are in short supply. Copper is one of these strategic materials. The price of copper (in terms of constant 1975 dollars) has more than doubled, while the cost of raw materials for glass (also in terms of 1975 constant dollars) has remained constant. There are sufficient raw material reserves for glass in the U.S. to last for an estimated 100 years. The cost of petroleum base products has risen in a manner similar to that of copper and thus has caused the costs of fiber optics protective cabling to double. Almost all laboratory and test bed demonstrations utilize single mode cables in conjunction with IOCs by 1981.

By 1983, low-loss (< 5 dB/km) long distance fiber-optic cables are a reality. The Corning Glass Co. is in a full production mode for the production of single mode fiber-optic cable. American Telephone & Telegraph Co., the principle receiver of Corning's output, begins replacement of one million feet of aging coax and twisted pair cabling. Six million feet of fiber-optic cable is produced in 1983. One million feet of cable will be replaced during each of the first two years. This replacement rate will be increased to five million feet per year in 1985. During the period of the mid-1980's, fiber-optic applications boom, but the largest users are companies in the communication industry. In retrospect, it can be seen that technology development rates during the late 1970's and early 1980's were quite significant. However, production growth rates were almost stagnant by comparison. Industrial producers utilized their pilot operations to produce only enough to satisfy occasional customers such as the military, and experimental laboratories. In the early 1980's, the military began to design avionics systems for single mode data bus applications. Twelve million feet of fiber-optic cable are produced in 1986. By 1987 there is increasing fiber optics applications by computer companies, electric power companies, aerospace industries, civil aviation firms, etc. This continuous demand helps maintain a stable production growth rate of 50 percent

per year. In 1988, 23 million feet of fiber-optic cable are produced. Component prices start a continuous decline over a period of time in accordance with the experience curve theory as explained in this thesis. Total industry output is 46 million feet of cable per year in 1990.

b. Scenario II - A Modestly Optimistic Context

During FY 1977, interest in fiber-optic systems has increased to the point that other follow-on fiber optics demonstrations are planned. The successful A-7 ALOFT Demonstration has proven the technical feasibility of point-to-point multimode applications. The cost models developed by NPS and NELC are utilized by analysts who conclude that single mode applications will be used in yet to be determined future military aircraft. The resounding success of the A-7 ALOFT Demonstration has helped pave the way for a similar demonstration with the Air Force's F-15. Funds have been made available for the Air Force Avionics Laboratory to replace the conventional coax data bus system of an operational F-15 with a fiber-optic data bus system. Prototype T-couplers and modular hybrid cricuits are used with multimode fiber-optic cables. One million feet of fiber-optic cable is produced in 1977. In early 1978, infrared light emitting diodes are beginning to be replaced with laser injection diodes for laboratory applications. Monolithic integrated LED circuits are introduced as standardized fiber-optic

components in 1978. In early 1979, the prototype 2000-ton Surface Effects Ship (2KSES) demonstrates the feasibility of a fiber-optic data bus system using multimode fiber-optic cables. It is decided that future data bus applications will utilize a single mode fiber-optic cable in conjunction with IOCs. Multimode cables will not be used in operational aircraft avionics systems. The decision is made in 1979 to utilize a single mode data bus system in the VPX (replacement for the P-3). The aircraft is to be built in the mid-1980's. In 1979, monolithic integrated optical circuits have been perfected and are available commercially. However, they won't be mass produced until the American Telephone and Telegraph Co. begins use of fiber optics in 1983. Even though interest is high, demand for fiber-optic components does not warrant full scale industrial production. The fiber-optic cable producers can keep up with demand with only a few production hours each day. Total production is four million feet of cable per year in 1980. By 1980, standardization of components has been completed. Single mode cable connectors have been successfully demonstrated for three years. By 1981, integrated optical circuits are off-the-shelf items but supply is limited because they are not full production items. However, their continuing successful use in laboratory applications indicate that the real future of fiber optics continues to point to integrated optical circuits

together with single mode cable as the desired goal of fiber optics technology. The successful Air Force F-15 Demonstration in 1981 has further convinced the Navy and Air Force to plan future avionics systems around the single mode data bus concept. The B-1 bomber demonstration in 1982 was a success. The application of fiber optics helped reduce total weight by six hundred pounds yet provided ample EMP/EMI protection. The Army starts replacing five million feet of tactical communication line in 1982. Army plans call for a replacement of 16 million feet of 26 pair coax cable by 1985. This will be followed by the replacement of 25-50 million feet of permanent long distance communication lines by 1990. In 1982, demand for low-loss single mode cable by the Army accounts for almost 50 percent of the total U.S. demand (4 million feet per year). The Army's share of the user market will dwindle to only a few percent per year after AT&T starts its replacement program. By 1983, AT&T is using ten million feet of single mode cable each year. 1983 is considered the base production year with a total production of 8 million feet per year. Russia, Japan and European countries are also active in the fiber optics market. Empirical data can now be gathered to verify growth rates of approximately 50 percent per year. In 1984, the VPX aircraft is built. It utilizes single mode fiber optics. In 1985, AT&T has the only data link system capable of handling

the high data rates required for a data bused "wired city" concept. A few strategically placed buses in a city are capable of transmitting data at the gigabit level. Other telecommunication companies prepare to follow AT&T's lead. By 1986 they are installing their own fiber-optic lines. After the additional telecommunications companies enter the market, production growth rates steady at 50 percent per year as total production is now 20 million feet of fiber-optic cable per year in 1986. Total production is 45 million feet of cable per year in 1988, 100 million feet per year in 1990. Newly constructed military aircraft avionics systems all use the fiber-optic data bus concept by 1989. New ships also use fiber-optic data bus. Total military usage is approximately five million feet per year, or only a fraction of the total used by the major communications companies.

c. Scenario III - a Modestly Pessimistic Context

Flight testing of the A-7 ALOFT Demonstration aircraft has neither proved nor disproved any of the claims of hopeful proponents of fiber-optic systems. Results from the Delphi questionnaire were somewhat late in being received. This, coupled with a less than satisfactory data collection for the life cycle cost model, has delayed the proposed economic analysis for a period of several months. The decision points on whether or not to use fiber optics in the avionics

packages of the proposed LAMPS helicopter, VPX (P-3 replacement), TASES (ES3's), and VPX (F-14 fighter follow-on), pass without a conclusive economic analysis from the ALOFT Demonstration. The decision is made to continue to use known reliable coaxial systems in the above mentioned aircraft. One reason given by military planners is that the SALT II Agreements with the Russians, among other things, were so successful that the needs of EMP/EMI immunity are no longer a driving force. It has also been argued very successfully by newly formed coaxial cable manufacturers' lobby groups in Washington that the coax/twisted pair data bus system of the F-15 has functioned perfectly well for years. "Besides," they argue, "think of the thousands of productive workers who will be thrown out of work if coax is no longer used." Military planners decide to use protective shielding for EMP/EMI immunity if and when the need arises. In 1978, because of constant pressure from Congress to "cut the fat" out of the military budget, R&D funds for fiber optics research are "cut to the bone." The planned 2KSES shipboard application is cancelled. It is clear that the 1980-1987 generation of military aircraft avionics systems will not utilize fiber optics. In the period 1978-1985, NELC, the Air Force Avionics Laboratory, and the Army Electronics Command use their limited R&D funds to their best advantage in continuing to demonstrate

the technical feasibility of fiber optics applications as data transfer links. All technological developments, such as laser injection integrated optical circuits, single mode connectors, T-couplers, and Star-couplers are slowly standardized -- mainly as a result of the military's Tri-Service effort in this area. A firm production base is not yet established but, as components become standardized, and as more component firms enter the market, prices to consumers continue to drop. Between 1980 and 1982, production doubles to two million feet of cable (mostly single mode) as more potential users are beginning to follow the lead of American Telephone and Telegraph Co. In 1983, with production at four million feet of cable per year, AT&T begins to replace its first million feet of aged long distance communication line. 1983 is considered to be the base year for production. More telecommunication companies follow AT&T's lead in the late 1980's, mostly because the strategic aspect of copper availability has driven them to find a substitute cable. Copper prices have more than tripled since 1975 (constant 1975 dollars). Raw materials for fiberglass, on the other hand, are not strategic in nature and are available at about the same relative cost. The strategic nature of petroleum based products has tripled the cost of fiber-optic protective cabling. Production totals eight million feet of fiber-optic cable in 1986. The

mid- to late-1980's see constant growth rates of 30 percent per year. Total production is put at 22 million feet per year in 1990. This period in the late 1980's sees the military designing operational single mode data bus avionics systems for aircraft to be built in the early 1990's. The Army begins to replace the first segment (one million feet) of tactical communication line in 1987. The Army will replace all 16 million feet of its coax line by 1995.

The three scenarios presented are the authors' own perceptions of how the fiber-optic industry might develop. Some of the information contained in the scenarios, however, was obtained from a literature review and conversations with military and industry contacts. The scenarios provide a framework for hypothesizing how the fiber-optic industry might evolve over time. It should be emphasized that many more scenarios could be developed by varying relevant branch points or events such as technological advances and military and civilian demand requirements. To summarize some of the information provided in the three scenarios, the following graph (Figure 1-IV-5) represents the annual production demand quantities for Scenarios I, II and III for fiber-optic cabling by production year.

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LIFE CYCLE COSTING OF AN EMERGING TECHNOLOGY: THE FIBER OPTICS --ETC(U)

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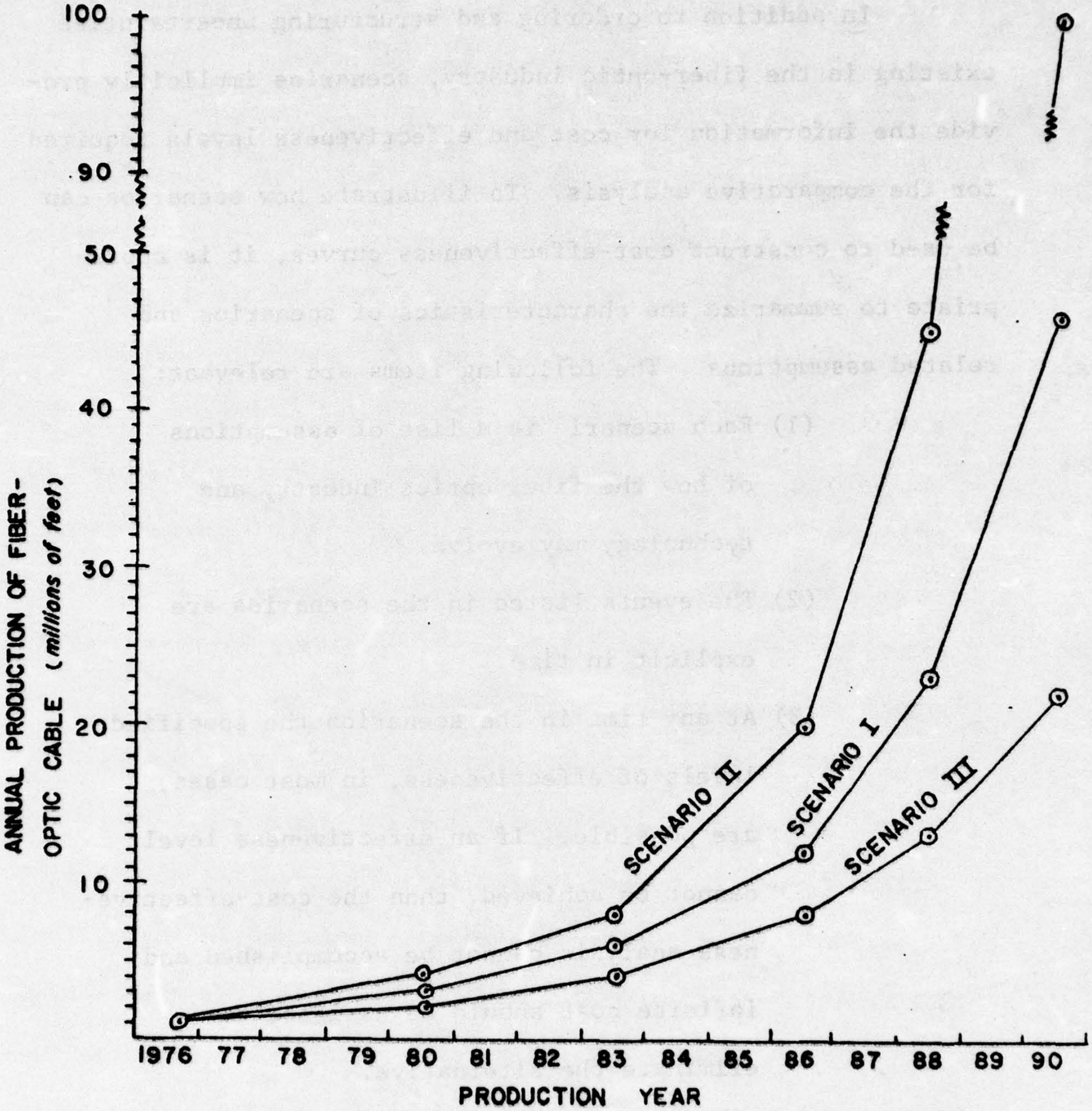

Figures I-IV-5. Fiber-optic cable demand, by scenarios

2. Constructing Cost-Effectiveness Curves from Scenarios

In addition to ordering and structuring uncertainties existing in the fiber-optic industry, scenarios implicitly provide the information for cost and effectiveness levels required for the comparative analysis. To illustrate how scenarios can be used to construct cost-effectiveness curves, it is appropriate to summarize the characteristics of scenarios and related assumptions. The following items are relevant:

(1) Each scenario is a list of assumptions of how the fiber optics industry and technology may evolve.

(2) The events listed in the scenarios are explicit in time.

(3) At any time in the scenarios the specified levels of effectiveness, in most cases, are possible. If an effectiveness level cannot be achieved, then the cost-effectiveness analysis cannot be accomplished and infinite cost should be assigned to eliminate the alternative.

(4) The cost of achieving a specified level of effectiveness are scenario and time dependent.

With these characteristics and assumptions it is possible to construct the matrices shown in Figure 1-IV-6.

SCENARIO A

EFFECTIVENESS LEVEL / YEAR	E_1	E_2	E_3	E_4	E_5
1976					
1977					
1978			C_{83}		
1979					
1980					

SCENARIO B

EFFECTIVENESS LEVEL / YEAR	E_1	E_2	E_3	E_4	E_5
1976					
1977					
1978			C_{83}		
1979					
1980					

Figure 1-IV-6. Scenario/effectiveness/time matrices

The elements of the matrices are the cost, C_{ij}, where i specifies the year and j the effectiveness level required. The rows of either matrix trace out the cost-effectiveness

curve for a particular year at five effectiveness levels. Possible cost-effectiveness curves for 1978 are constructed for scenario A and B in Figure 1-IV-7.

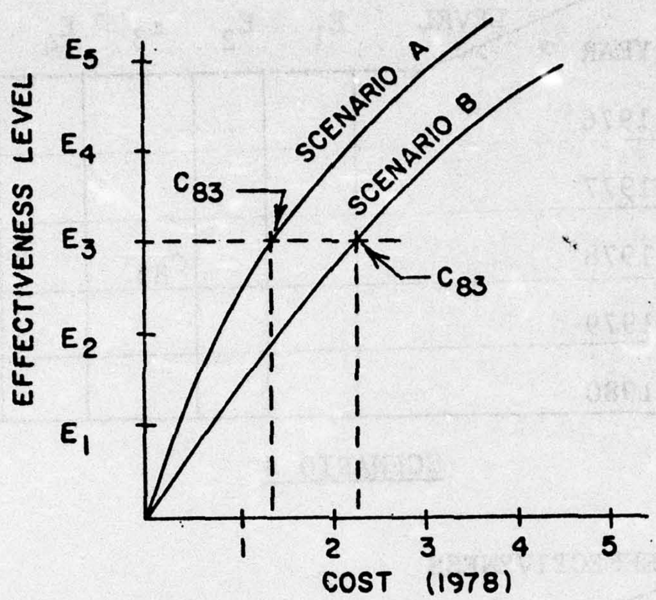

Figure I-IV-7. Scenario related cost-effectiveness curves

To illustrate how scenarios can be used to construct cost-effectiveness curves for the fiber-optic alternative, scenarios A and B are first defined. Assume scenario A depicts rapid technological advances, standardization of components, and high demand from the civilian community while scenario B represents continued research and development outlays, no civilian demand, and prototype components. If effectiveness level three is desired in 1978, then the C_{83} cost element should be computed for scenarios A and B utilizing the life

cycle cost model developed in Volume Two of this report, together with the assumptions of the respective scenarios. Since the scenarios contain demand quatities and growth rates for fiber-optic components, cost estimates can be made fo these components by utilizing the experience curve or other applicable techniques. Experience curves will be discussed in Section V-C. The component cost estimates then can be applied to the life cycle cost model to obtain the C_{83} cost element. Estimating costs for the five effectiveness levels and both scenarios results in the cost-effectiveness curves depicted in Figure 1-IV-6.

Scenarios, therefore, provide the basis from which cost estimates can be made. The selection of a particular scenario, from the many possible scenarios, should be assessed in terms of the likelihood of occurrence of particular scenarios. As a possible method of minimizing or limiting the number of scenarios and refining estimates contained in scenarios, the authors suggest using the Delphi technique to be discussed both in Section V-B and Volume Two.

V. TWO COSTING TECHNIQUES FOR FIBER OPTICS

A. GENERAL

In this section, two techniques for costing fiber optics are discussed. First, the Delphi technique is discussed as a method of obtaining estimates identified in and required for scenarios. These estimates include such items as demand quantities, growth rates, and technological advances. The second technique, the experience curve, is then explained. It permits the estimation of costs to the government based on cumulative quantity produced. This discussion is followed by a demonstration showing how the estimates contained in the scenarios can be applied to the experience curve to predict the future price behavior of fiber-optic components.

B. THE DELPHI TECHNIQUE

In fiber optics, data do not exist to establish firm technological, price or demand trends. In this case, regression, sampling, smoothing or other mathematical analyses are not applicable as a basis for forecasts. Hence, predictions must rely on the opinions of experts. Kahn makes the observation that many books go into considerable detail on the methodology of forecasting, particularly technological forecasting. While the methods seem very impressive when

viewed in terms of how successful they are, their track record is not as good as some of their proponents would suggest. (57) Kahn, however, expresses great interest in the Delphi method which he thinks has great potential in areas involving emerging technologies.

Kahn makes the statement that while Delphi is an excellent method of technological forecasting, it works best when it polls the experts who are actually attempting to achieve the given result. Not only will they have some idea when the innovation can be expected, but they could also have a large influence on program outcomes.

Delphi, as a technological forecasting technique, is generally credited to Olaf Helmer, T. J. Gordon, and N. C. Dalkey of the RAND Corporation. Initial work was done by Helmer as early as 1959. Helmer's publication of a "Report on a Long-Range Forecasting Study" by the RAND Corporation, in 1964, discussed the Delphi technique in detail. (45) In his report, he describes his now well known method of soliciting forecasts from a panel of experts in order to deal with specific questions, such as when will a new process gain widespread acceptance or what new developments will take place in a given field of study. Instead of the participants gathering together to discuss or debate the questions, they

are kept apart, usually answering assigned questionnaires through written or other formal means, such as on-line computers.

The advantages of using Delphi to poll the experts then are: (1) The Delphi seeks to systematically codify the opinions of experts while minimizing bias. (2) It polls the experts who are actually attempting to achieve the given results. (3) It eliminates typical problems of face-to-face interactions among members of a panel. Many of these problems are psychological factors which tend to reduce the value of methods based on face-to-face interaction (e.g., brainstorming sessions). (53) Some of these psychological factors are: unwillingness to back down from publicly announced positions, personal antipathy to or excess respect for the opinions of a particular individual, skill in verbal debate, band wagon effects of majority opinion, and persuasion. (7)

There are also disadvantages to Delphi. Some of these have been pointed out by Ayres and Cetron in their books concerning technological forecasting. (7) (16) These disadvantages include: (1) It is difficult to allow for the bias of the pollster. For example, the framers of the questions can to some degree guide the trend of the answers.

(2) Panel members dislike starting with a blank piece of paper. They also dislike being involved in extensive iterations and evaluating projections outside their areas of expertise. (3) Extensive iterations can result in a heavy investment in time and money to the researcher.

The authors have taken the above mentioned advantages and disadvantages into consideration in deciding to recommend Delphi as an appropriate technique to use in the costing of fiber optics. Primary reasons for the Delphi selection are: (1) Fiber optics is an emerging technology which is fraught with not only technological uncertainties, but also total demand uncertainty. In addition, there are component price uncertainties. (2) The experts in the fiber optics industry can be easily identified (see Appendix G). (3) Users and producers alike would benefit from the results of a Delphi study. It is to their mutual advantage to cooperate in efforts to realize the potential benefits of this emerging technology. (4) Improved forecasts or estimates of future demand quantities, industry growth rates, technological advances and component prices are expected to decrease the range of the estimates for these variables. As a result, the number of scenarios to be developed can be fewer since the range of estimates is smaller. Based on the above

considerations, the authors recommend a Delphic approach. Specifically, the authors make the following recommendations: (1) The first iteration should provide a firm starting point for participants by structuring events into sub-categories of technology, demand quantities, growth rates, and component prices. (2) The number of iterations should be limited to two or three unless further refinement is required. (3) The panelists should be required to self-weight themselves as to their expertise in evaluating events in any given field or sub-category of the questionnaire. These weights should range from 1 (highly qualified) to 5 (not qualified). (4) Construct the Delphi questionnaire format such that there is an interweaving of timing, producer feasibility, and user desirability. Timing is particularly important because of the heavy time dependence of scenarios. The feasibility and desirability aspects are particularly important to the producers and users respectively as they relate to their particular areas of expertise. (5) Panelists should be informed of the study plan and its schedule prior to involvement. They should also receive the final results of the study.

The Delphi questionnaire found in Appendix H, as developed by the authors, is meant to accomplish the above sugestions. It is

an example of how time, desirability and feasibility can be interwoven to form a simple, yet comprehensive, approach to establishing refined estimates for scenarios. The events are representative of the types of questions which should be included by one who conducts a Delphic study of an emerging technology.

C. EXPERIENCE CURVE

This section will develop experience curve theory and explain how it can be used as a forecasting technique to help predict the cost behavior of products such as fiber-optic cables, drivers (LEDs) and receivers. Experience curve theory should not be confused with the well-known learning curve theory. Learning curve theory predicts cost reductions for two cost elements, labor and production inputs (materials), whereas experience curve theory predicts cost reductions for all cost elements including labor, development, overhead, capital, marketing, and administration. Experience curve theory is much broader a concept that incorporates learning curve theory. To facilitate the development of experience curve theory, the subsequent discussion will explain both theories noting similarities, differences, and the factors which explain both theories.

Both the experience curve and learning curve theories are expressed as cost quantity relationships stating that each time the total quantity of items produced doubles, the cost per item is reduced to a constant percentage of its previous cost. For example, if the cost of producing the 200th unit of an item is 80 percent of the cost of producing the 100th item, and if the cost of the 400th unit is 80 percent of the

200th item, and so forth, the production process is said to follow an 80 percent unit experience or learning curve. Figure 1-V-1 shows a unit curve for which the reduction in cost is 20 percent (i.e., 80 percent of the original cost) with each doubling of cumulative output. The arithmetic plot illustrates that the reduction in cost for each unit is very pronounced for early units. For example, on the 80 percent curve, cost decreases to 28 percent of the original value (100) over the first 50 units. Over the next 50 units, it declines only 5 more percentage points to 23 percent of the first unit cost. A plot of the same relationship on a log-log scale, as shown in Figure 1-V-2 makes the relationship linear and reflects the constant rate of reduction. Log-log plots are used almost exclusively because the straight-line relationship is easier to construct and use for predictive purposes.

The mathematical relationship between cost and quantity for experience curves and learning curves is represented by the power equation:

$$C_n = C_1 n^{-\lambda} \qquad \text{Equation (1)}$$

where: C_1 : is the cost of the first unit

C_n : is the cost of the nth unit

n : is the accumulated units produced (experience)

λ : is the rate at which cost declines with experience (slope of the experience curve).

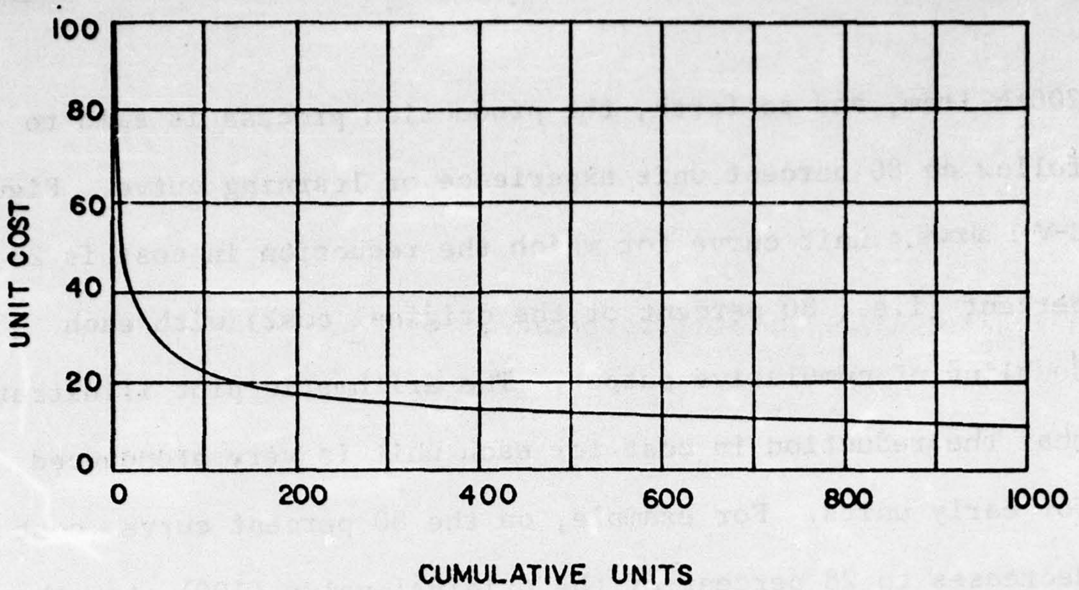

Figure I-IV-1
The 80% experience curve on an arithmetic grid

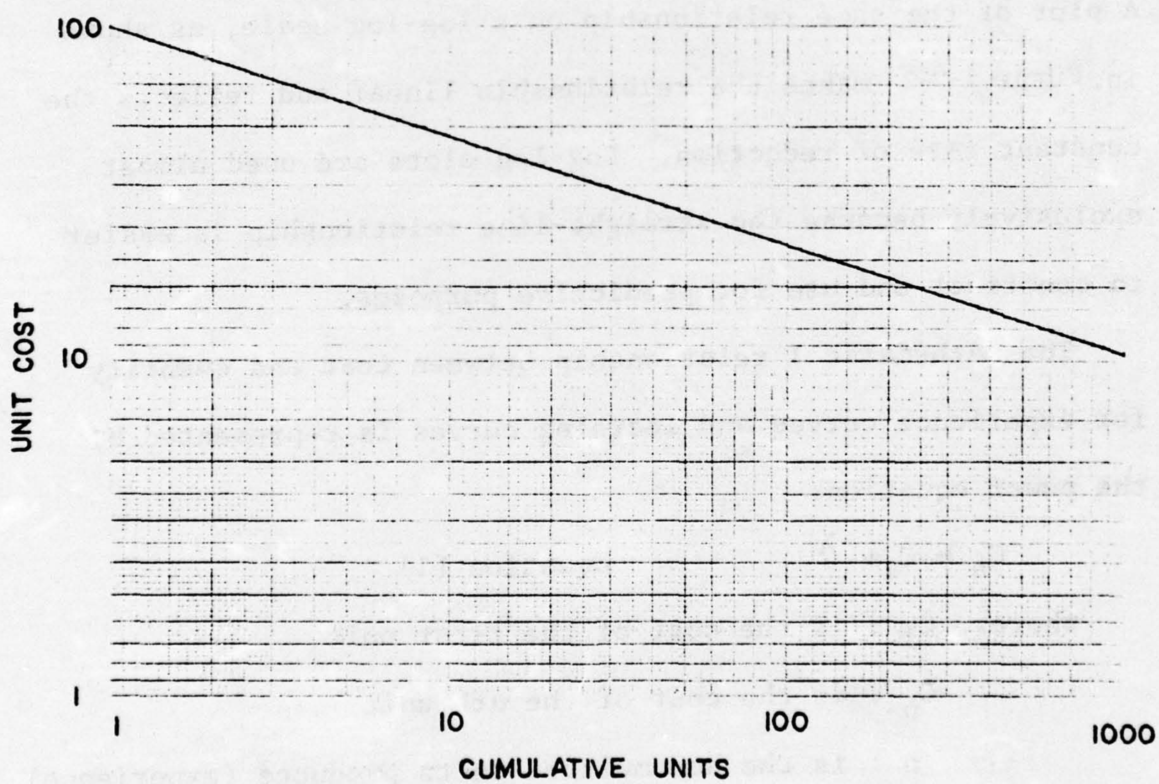

Figure 1-V-2
The 80% experience curve on a logarithmic grid

The slope of the experience curve, λ, bears a simple relationship to the constant percentage to which cost is reduced as the quantity is doubled. By letting S represent the fraction to which cost decreases when quantity doubles, and using Equation (1), then:

$$S = \frac{C_{2n}}{C_n} = \frac{C_1(2n)^{-\lambda}}{C_1(n)^{-\lambda}} = 2^{-\lambda}$$

$$S = 2^{-\lambda} \qquad \text{Equation (2)}$$

$$\lambda = -\frac{\log S}{\log 2} \qquad \text{Equation (3)}$$

For example, an experience curve with a slope of $\lambda = 0.415$ has a constant percentage reduction in cost to 75 percent of its previous cost each time accumulated quantity doubles. In order to avoid confusion, subsequent use of the term "slope" will refer to the constant percentage reduction.

The history of learning curve theory dates back to 1925 when, in the aircraft industry, learning patterns were first observed by the Commander of Wright-Patterson Air Force Base. The phenomonon observed was the constant reduction in direct labor hours required to build airplanes as the number of aircraft built doubled.(50) Subsequently, learning curve theory has been documented and used in many industries to predict

cost reductions for direct labor and raw material -- or production inputs. Typical learning curve slopes have ranged from 75 to 90 percent. Some of the factors commonly mentioned that account for direct labor and material cost reductions are summarized as follows:

(1) Job familiarization by workmen. This results from the repetition of manufacturing operations.

(2) General improvement in tool coordination, shop organization, and engineering liaison.

(3) Development of more efficiently produced sub-assemblies.

(4) Development of more efficient tools.

(5) Substitution of cast or forged components for machined components.

(6) Development of more efficient parts-supply systems.

(7) Improvement in overall management.

(8) Workmen learn to process the raw materials more efficiently, thereby cutting down spoilage and reducing the rejection rate.

(9) Management learns to order materials from suppliers in shapes and sizes that reduce the amount of scrap that must be shaved and cut to form the final product.

The above list of relevant factors is not considered complete. It also tends to understate the importance of the one item usually considered most important -- labor learning. (86)

Experience curve theory dates back to 1965.(12)* Experience curve theory is much broader in scope than learning curve theory. It considers the full range of costs which include development, capital, administration, marketing, overhead, as well as labor costs. Raw material cost is not included in this list. The cost of raw materials usually depends on factors such as availability of supply. For example, the price of unprocessed timber fluctuates from year to year partly as a result of federal policy concerning the nation's timber reserves. Strictly speaking, correct measurement of the experience effect therefore requires that expenditures be calculated net of the cost of raw materials, i.e., on value added to the product. In general, experience curves do not apply if major elements of cost, or price, are determined by patent monopolies, natural material supply, or government regulation. The experience curves apply to products

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* Experience curve theory is primarily credited to Mr. Bruce Henderson, founder and President of Boston Consulting Group, Inc., a management consulting firm specializing in developing corporate strategy.

in industries with multiple producers who interact rivalously as well as other products in purely and perfectly competitive industries. Experience curves cost reductions on value added range from 20 to 30 percent every time total product experience (accumulated quantity) doubles for an industry as a whole, as well as for individual producers. These reductions represent experience curve slopes of 70 to 80 percent. Empirical data have been collected which verify these experience curve slopes of 70 to 80 percent. Many of these data collection efforts were for products in the chemical and electronics industries. Reports of the Electronics Industry Association, the Manufacturing Chemists' Association, and the 1965 Statistical Supplement to the Survey of Current Business by the United States Department of Commerce, among others, were used in gathering these data, as were Boston Consulting Group sources within the relevant industries. Figure 1-V-3 on integrated circuits and Figure 1-V-4 on polyvinylchloride are two examples illustrating the experience curve effect with the characteristic cost reductions. To permit comparability over time, prices were expressed in constant 1958 dollars.

Price and experience (accumulated quantity) follow one of two characteristic patterns: stable, as shown in Figure 1-V-5, or unstable, as shown in Figure 1-V-6.

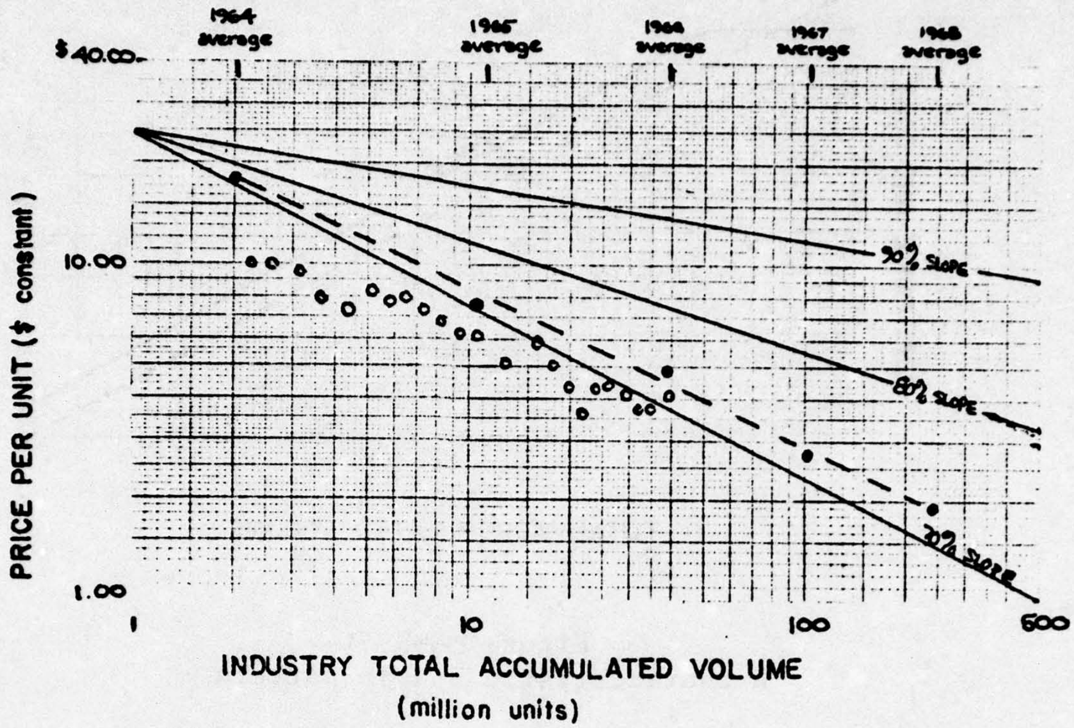
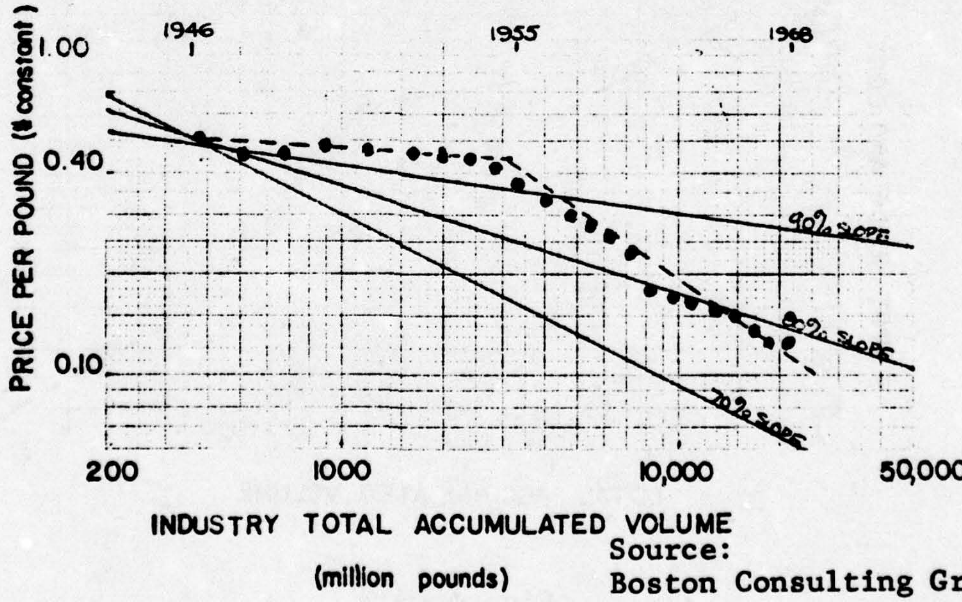


Figure 1-V-3
Integrated circuits experience curve



Source:
Boston Consulting Group

Figure 1-V-4
Polyvinylchloride experience curve

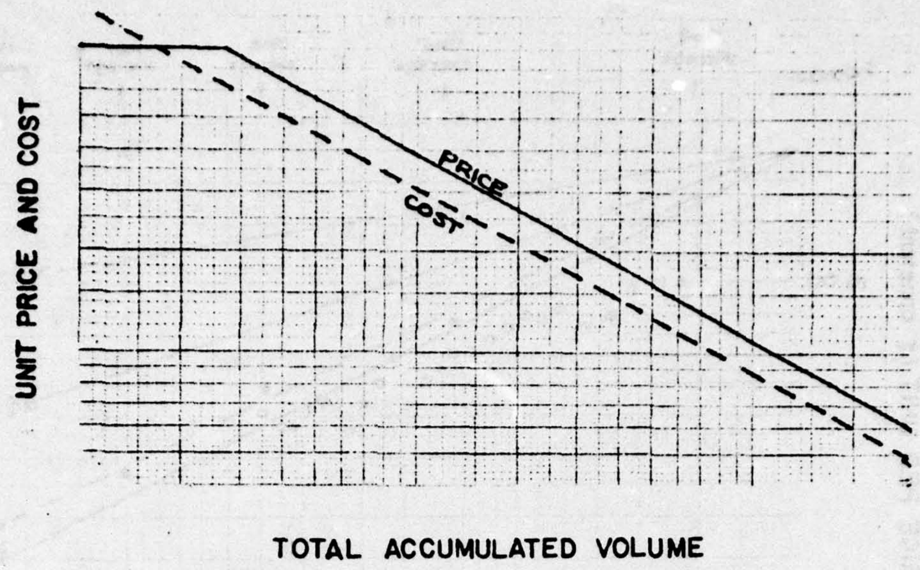


Figure 1-V-5
A characteristic stable pattern

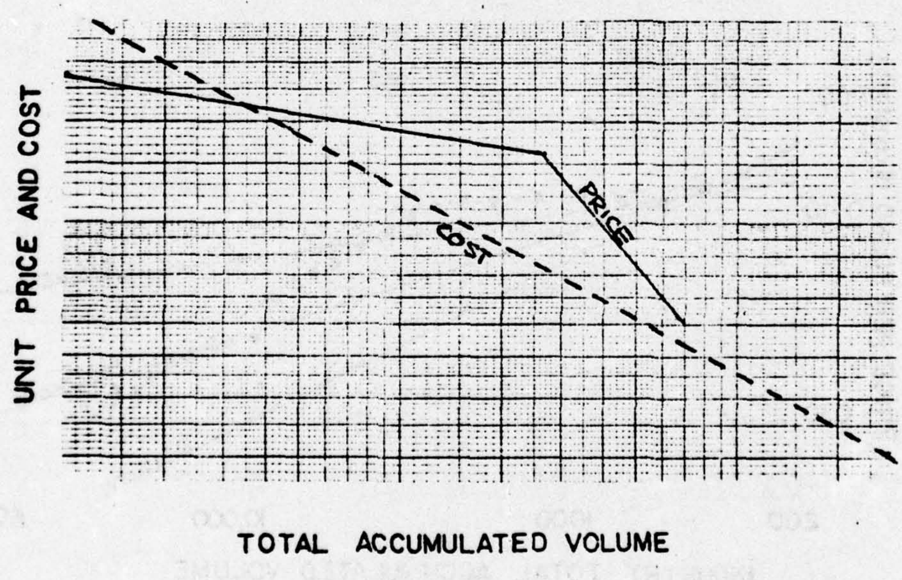


Figure 1-V-6
A typical unstable pattern

A stable pattern exists when the cost and price of a product maintains a constant quantitative difference over time. In Figure 1-V-5, price and cost parallel each other over time thus indicating a stable pattern. Products following this type pattern tend to be found in technological industries which are experiencing rapid growth as well as being very competitive. Integrated circuits is an example of such a product. Its straight-line trend relationship is illustrated in Figure 1-V-3

When prices do not decline as rapidly as cost, an unstable pattern, as shown in Figure 1-V-6, will exist. Prices are set below cost to establish an initial market. As volume and experience reduce cost, the prices are maintained, gradually converting the negative margin to a positive one. If prices do not decline as fast as costs, then competitors are attracted to enter the market. At some point, prices do start to decline faster than costs. The experience curve for Polyvinylchloride, as shown in Figure 1-V-4, illustrates the point. Obviously, prices cannot decline faster than costs indefinitely. At some point, a reverse bend in the price curve reestablishes a stable relationship between cost and price. Figure 1-V-7 illustrates an unstable pattern transforming to a stable pattern in different phases.

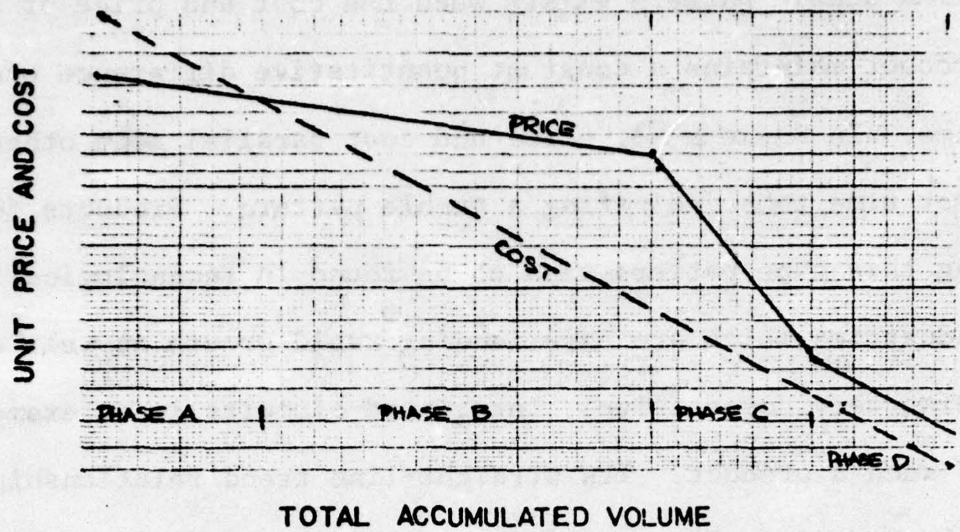


Figure I-V-7
A characteristic unstable pattern
after it has become stable

In Phase A, costs typically exceed prices. This is always the case in the very early production stages of a new product. It covers an extensive period if the future potential is obvious and competition appears severe in the very early life of the product.

In Phase B, the market leader is effectively holding a price umbrella over higher cost producers who are entering the market and increasing their market share. In effect, the dominant producer is trading future market share for current profits.

Phase C is a shakeout period. This phenomenon is caused when a producer thinks that his own interests will be better served by lowering the price faster than industry costs are declining. The typical slope of the experience curve during this phase is about 60 percent during the period in which industry experience doubles. This, in fact, does not occur unless the cost-price relationship is unstable. An unstable market is characterized by rapid growth, a large number of producers, and a large difference between price and cost for the lowest cost producer. The motivating factor for the lowest cost producer to lower his price is to increase his market share. High cost producers must then either accept lower profit margins or drop out of the industry.

At the end of the shakeout phase, the stability of the relationship of cost to price is fully established and Phase D, i.e., stability, emerges.

The factors, identified by the Boston Consulting Group, that cause the experience curve effect include:

(1) The "learning curve effect"

(2) Competition (rivalry) among producers in a given product market

(3) Economies of scale and specialization; the "scale effect"

(4) Investment in capital to reduce cost and increase productivity.

The learning effect, people learning by doing, has already been discussed in learning curve theory and is the major factor which causes reductions in labor costs. The second factor, competition (rivalry) among producers, forces each producer to find means of lowering his total average costs in relation to his competitors. The successful low-cost producer will then be able to lower his prices and induce a situation which causes a "shakeout" of those producers who have been unsuccessful in reducing costs. This will give the low cost producer an increased market share. With increased market share, the third factor, economies of scale, can be realized. With scaled-up volume due to increased market share, it is possible to use more efficient tools and spread their cost over enough units so that both labor and overhead costs are reduced. Increased volume may also make it possible to consider alternative materials and alternative methods of manufacture and distribution which are uneconomic on a small scale. The final factor, investment in capital, is a further attempt to reduce cost by displacement of less efficient factors of production. This can be accomplished by automating various stages of production thus reducing labor costs. This may not be

possible or desirable if the market share is not sufficient to warrant the investment.

To use the experience curve as a predictive tool the following elements are required:

(1) C_1 - first unit price

(2) Initial experience (accumulated quantity), represented by C_1

(3) The slope of the experience curve.

With these three elements it is an easy matter to construct an experience curve on a log-log plot. As a hypothetical example for low-loss fiber-optic cable, an initial price of $4.00 per foot with an initial experience of 100,000 feet is assumed. Experience curve slopes of 70, 80, and 90 percent are plotted to illustrate a range of cost reductions possible. Figure 1-V-8 illustrates the three experience curves with their different slopes. The initial point (100, $4.) is common to all three experience curves. A second point for the 70 percent curve is obtained by multiplying (.70) (4.00) = $2.80. This $2.80 figure is for the doubled quantity of 200. Hence the second point (200, $2.80) is obtained and a straight line is constructed to complete the curve. The 80 and 90 percent curves are constructed in like manner.

These curves illustrate how prices might decrease as a function of accumulated quantity but they do not indicate when these price/quantity relationships will occur. Time frames can be established if the rate of growth of the accumulated quantity is known. Use of the standard formula for annual compound interest is applicable. The formula is:

$$A = (1.00)\ (1 + i)^T \qquad \text{Equation (4)}$$

where: i : is the annual interest rate

T : is the time in years \$1.00 has been invested

A : amount accumulated after T years.

Changing Equation (4) to multiples of accumulated quantity produced and using growth rate in place of interest rate yields the new formula:

$$mA = A\ (1 + g)^T \qquad \text{Equation (5)}$$

where: m : is the desired multiple of any accumulated quantity produced

A : accumulated quantity produced

g : annual growth rate of the product

T : years required to attain the desired multiple.

Solving Equation (5) for T provides the desired result:

$$T = \frac{\log m}{\log\ (1 + g)} \qquad \text{Equation (6)}$$

For example, the time to double accumulated quantity (m = 2) having a growth rate of 40 percent per year (g = .4) is

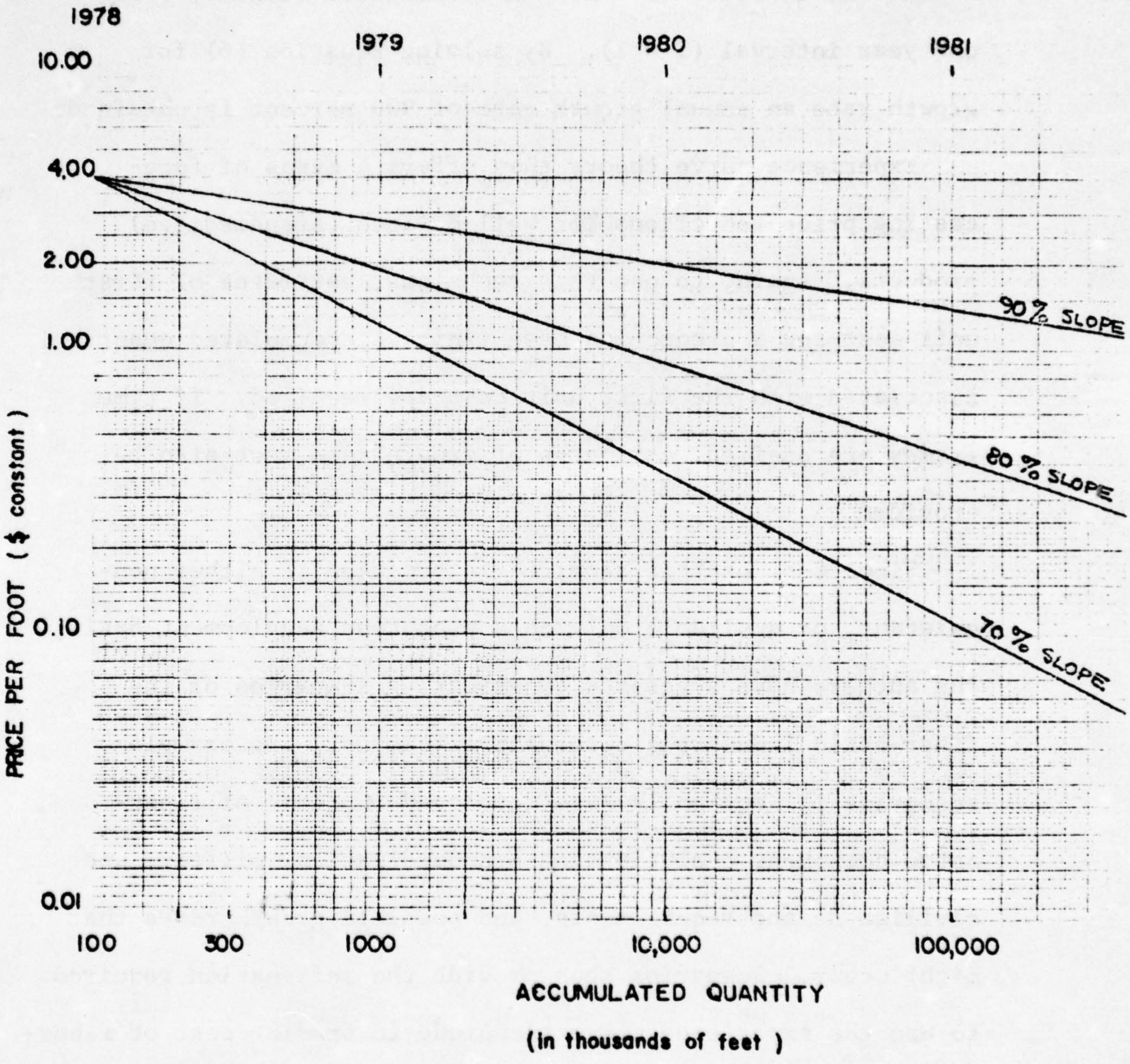


Figure 1-V-8
Hypothetical example of a fiber-optic cable experience curve

approximately two years. Figure 1-V-8 indicates (hypothetical) a ten-fold increase (m = 10) in accumulated quantity each one year interval (T = 1). By solving Equation (6) for growth rate an annual growth rate of 900 percent is obtained.

Experience curve theory then offers a means of forecasting price reductions for well-defined (standardized) products. Again, to use this technique, estimates of first unit cost and a production base (initial accumulated quantity) associated with the first unit cost are required. If time frames are desired, estimates of growth rate must also be provided.

Since most of this required information is either nonexistant, or available only on a prototype development basis, the authors have suggested constructing scenarios of the fiber-optic industry's alternative futures. The example scenarios in Section IV were developed in terms of fiber-optic component evolution and standardization, military and civilian demand requirements, and possible growth rates that might occur. Scenarios thus provide the information required to use the experience curve technique to predict cost of fiber-optic system components such as cable, drivers (LEDs) and receivers. These component cost estimates could then be used as inputs to the life cycle cost model.

VI. SUMMARY AND CONCLUSIONS

This volume contains the results of the initial cost-effectiveness investigation of the fiber-optic alternative for an avionics data link system. The study was intended as an initial approach toward the desired objective of numerical estimation of fiber optics avionics data link life cycle costs.

The historical and technological background of fiber optics as well as the background of the A-7 ALOFT Demonstration was discussed. A general discussion of a cost-effectiveness analysis was presented together with possible measures of effectiveness for data link systems.

Scenario-writing was discussed as a means of ordering the uncertainties of this emerging technology. Sample scenarios were developed by the authors to provide specific time-related estimates as to civilian/military demand, growth rates, standardization and technological development in fiber optics. These representative scenarios are meant to be examples of scenarios which can be established as a base for making cost estimates.

Two specific forecasting techniques, Delphi and experience curves were discussed as relevant to the costing of this

emerging fiber optics technology. A Delphi questionnaire is proposed as a means of soliciting forecasts from a panel of experts in order to deal with the specific uncertainties associated with fiber optics. Experience curves were suggested as a means of predicting the cost behavior of products such as fiber-optic components.

It is the basic conclusion of the authors that: (1) These techniques, scenario-writing, Delphi and experience curves, can be combined as a cost-predictive method to estimate component prices in an emerging technology such as fiber optics. (2) Meaningful component cost predictions can then provide a means of estimating reliable costs for the life cycle cost model elements used in a cost-effectiveness study. (3) At the present time, the uncertainties associated with future cost estimates of fiber-optic components, uncertainties of demand and production, and lack of standardization will require careful analytical work if reasonably accurate life cycle cost estimates are to result. (4) The emerging fiber optics technology deserves full and continuing effort and attention by R&D agencies. Even if the results of initial cost-effectiveness studies are such that the decision is made to <u>not</u> use fiber optics

in next generation aircraft, it would be a mistake to cut back or reduce fiber optics R&D funding. Future military communication and data link systems may well be the beneficiaries of today's development efforts.

VOLUME TWO

I. INTRODUCTION AND INVESTIGATIVE APPROACH

A. PURPOSE AND BACKGROUND

The major purpose of this volume is to develop an appropriate life cycle cost (LCC) model to support the economic analysis of the A-7 Airborne Light Optical Fiber Technology (ALOFT) Project identified in Volume One.

The A-7 ALOFT project is being planned and implemented by the Navy to: (1) confirm that fiber optics is a practical interface technology for internal aircraft signal transmission, and (2) demonstrate the feasibility of an electro-optic transmission system in a typical present day avionics suite through a full scale system application and evaluation.

In brief, the A-7 ALOFT project consists of an extended ground and flight test demonstration of an A-7 navigation and weapons delivery system, (N/WDS) in which the signal wiring will be replaced with fiber optic data cables. Three hundred two twisted pair wires which interconnect the ASN-91 tactical computer and 9 remote units will be replaced by 13 fiber optic cables. This will be accomplished by incorporating time division multiplexing and fiber optic interface circuits to interconnect the N/WDS system. Information transmitted on the fiber optic channel is time division multiplexed and encoded into non-return to-zero Manchester format. The encoded data modulates the current source for a light emitting diode (LED) which transforms the electrical signal to an optical analog which is transmitted via the fiber optic calbe to a PIN photo diode where the optic signal is transformed back to electrical format, decoded and demultiplexed. In sum, the A-7 ALOFT demonstration utilizes state-of-the-art fiber optic technology to link a present day avionics system of remote sensors, command/control equipments and peripheral processors to a general purpose tactical computer.

An A-7 ALOFT economic analysis to compare the total system costs and performance benefits of this fiber optic system configuration to existing or proposed alternative wire interconnect designs is being conducted concurrently with

the A-7 ALOFT demonstration. NELC Technical Document 435, "A-7 ALOFT Economic Analysis Development Concept," J. R. Ellis and R. A. Greenwall, 7 July 1975, (33) outlines the approach, assumptions, and program plan for the conduct of the anlysis. Under this concept, a cost benefit analysis is being conducted, coordinated and directed by NELC through the joint efforts of the McDonnell Aircraft Company (MCAIR), and the Naval Postgraduate School (NPS). To support this required analysis effort, the NPS has been primarily tasked to develop and provide an applicable LCC model for the economic analysis and costing methodology for fiber optics. Volume One provided an initial investigation of fiber optic technology and outlined an initial approach to estimating life cycle costs of fiber optics by utilizing Delphi and experience curve techniques in conjunction with ordered scenarios. This volume is a NPS follow-on-study directed primarily at the development of a LCC model to support the A-7 ALOFT economic analysis. An initial data collection effort has been conducted by the NPS and is included as Appendix I.

B. A-7 ALOFT ECONOMIC ANALYSIS

The A-7 ALOFT Economic Analysis Development Concept, NELC TD 435, establishes the requirement and framework for the A-7 ALOFT economic analysis which will compare total system cost and performance benefits for the specified fiber optic/ coaxial cable alternatives under consideration. The economic analysis program plan consists of three major steps:

1. Develop life cycle cost estimates for each alternative.

2. Identify and quantify the benefits for each alternative.

3. Conduct a cost benefit analysis to compare, test, rank, and evaluate the alternatives.

The A-7 ALOFT economic analysis is currently as a continuous cycle of the above steps, utilizing development and analytical feedback to improve and update the quality and accuracy of the continuous analysis within time and fiscal constraints.

The baseline configuration for this analysis is the A-7 ALOFT configuration consisting of signals listed in Appendix B of NELC TD 435.(33) The baseline configuration is representative of a small fighter attack aircraft navigation and weapons delivery system (N/WDS) with parallel-to-serial electronic multiplexing. The hypothesis of the analysis is to assume the pre-existence of the necessary electronic multiplexing for each alternative so that the only determination is whether to select coaxial cable or fiber optics as the point-to-point interconnect system. The alternative of twisted pair components was discarded due to inability to handle high data rates without extreme susceptability to electromagnetic compatibility (EMC) problems.

The objective of the analysis is to compare total cost and performance benefits of the alternatives in order to support design and development decisions concerning the choice of a future avionics interface system. The economic analysis is also intended to provide the analytical basis for total aircraft fiber optic system projections and a

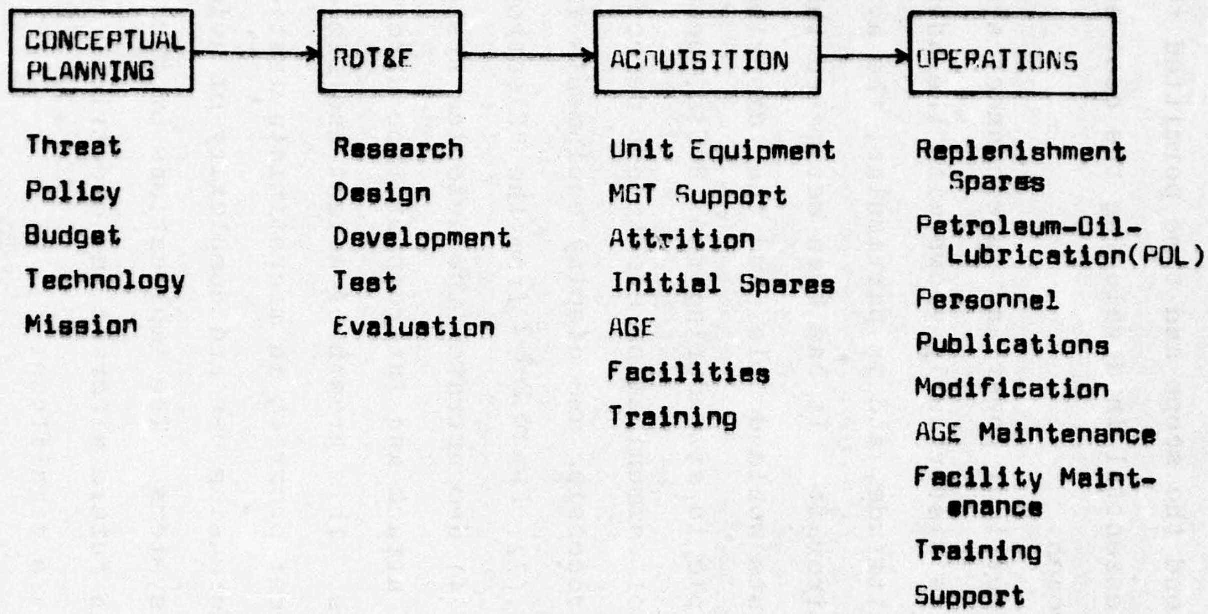
planned FY 77 cost benefit analysis of fiber optic data bus system design alternatives.

NELC TD 435 should be referenced if a more detailed description or additional information concerning the economic analysis plan, organization, tasks, schedule, or deliverables is desired.

C. THE FIBER OPTIC DEVELOPMENT DECISION

The A-7 ALOFT economic analysis is being conducted to identify and evaluate the life cycle costs and benefits associated with a fiber optic point-to-point aircraft data transfer system in order to determine whether a follow-on full scale development program is warrented and can be justified. For purposes of cost estimating and discussion, the fiber optic development program can be described as an aircraft subsystem acquisition, consisting of conceptual, development, production and operational phases. A disposal phase will not be considered since each system is estimated to have a physical life greater than or equal to the specified 10 year economic life. Figure 2-I-1outlines the sequence of these phases and identifies the basic functional elements within each. The A-7 ALOFT Project is a conceptual effort to develop, evaluate, and demonstrate the feasibility of a fiber optic data transfer system, and though an economic analysis determine the cost benefit tradeoffs needed to decide whether a full scale development should be undertaken.

The impetus for the A-7 ALOFT program rests in the potential of fiber optic technology to solve major aircraft



PROGRAM LIFE CYCLE PHASES

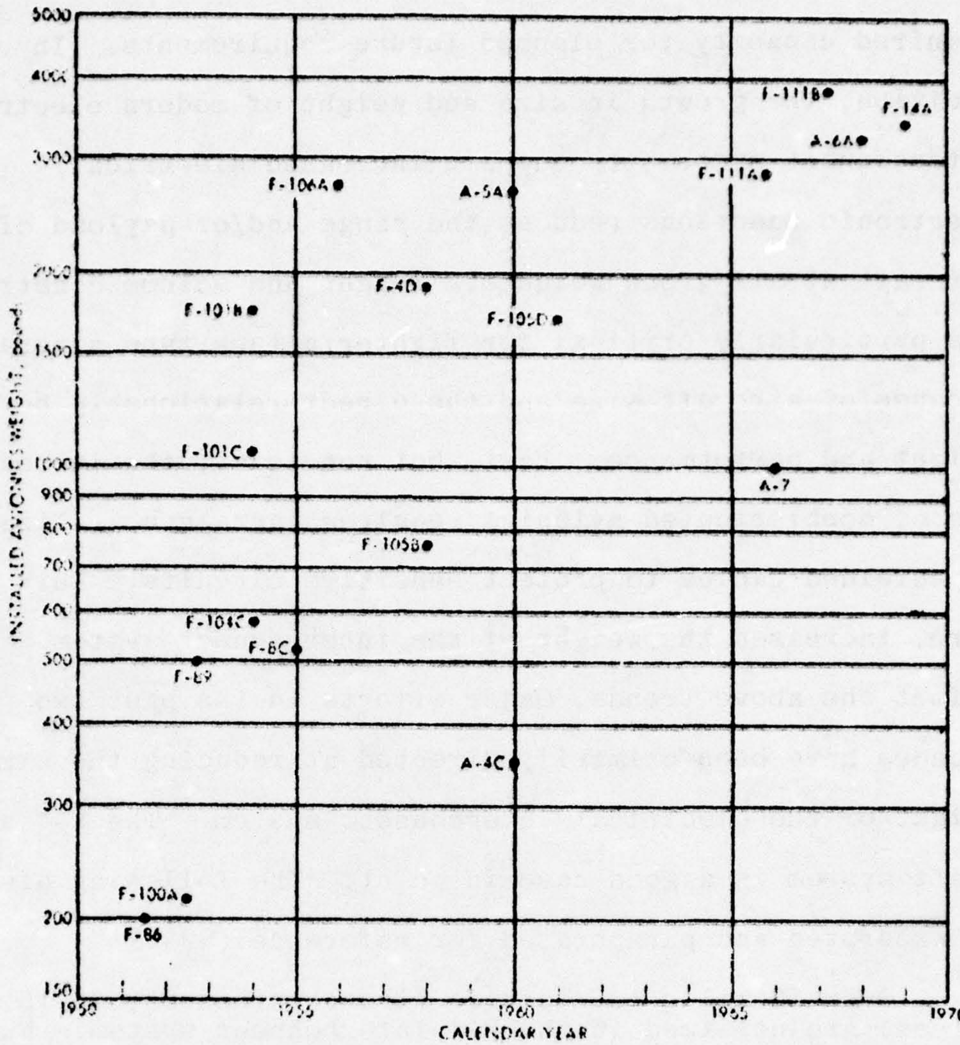
SOURCE: The BOEING Company publication D180-17648-1

Figure 2-I-1

interconnect system problems, reduce the weight and volume of the interconnect system, and improve system performance. Although a complete investigation of aircraft interconnect problems is beyond the scope and time permitted this study, an overview is essential in developing the cost estimating analytical approach.

Aircraft electrical power and interconnect system requirements have historically grown with the advances in speed, range, altitude, and in particular, the avionics capability of aircraft. It has been estimated that aircraft power requirements would double, and that distribution networks would triple in size during the 1970's, because of the increasing use of communication electronic detection, countermeasure, data processing and display equipments in aircraft weapons systems.(72) Figure 2-I-2 from the "Electronics X Study,"(43 and 44) demonstrates the avionics system weight growth trend in attack and interceptor type aircraft in the last two decades. This growth of weight and size has occurred despite concurrent progress in microminiaturization and reflects the increasing use and complexity of avionics in modern weapons systems. The implications of the above growth trends on future aircraft and electrical interconnect system design, are significant.

First, and of primary importance, is the increasing dependence of the military mission on the installed electric/electronic system. This trend is expected to continue and increasing avionics requirements required growth in both



Avionics System Weight Trend in Attack and Interceptor Aircraft.

Source: Electronic "X"

Figure 2-I-2

the size and capacity of interconnect systems. It is projected that current wire interconnect systems will not afford the required capacity for planned future requirements. In addition, the growth in size and weight of modern electrical interconnect systems to support increased electrical/electronic functions reduces the range and/or payload of the aircraft at all gross weights. Weight and volume constraints are particularly critical for fighter/attack type aircraft because of aircraft size and the direct relationship between weight and performance. Last, but not least, the increased use of sophisticated avionics requires increased utilization of shielded cables to protect sensitive circuits. This in turn, increases the weight of the interconnect system. To offset the above trends, major efforts in the past two decades have been primarily directed at reducing the size and weight of the electrical interconnect system. The F-4 aircraft system is a good case in point. The following history is excerpted and paraphrased for reference (90):

> Over 12 miles of electric wire (bewteen 65,000-75,000 feet) are utilized in the F-4 interconnect system. When introduced in the early 1960's, the F-4 Phantom utilized a conventional wiring installation with a 22 mil insulation wall which weighed 4.70 pounds per 1000 feet. This electical wire harness was so large that installation and repair proved difficult. A search for new materials and techniques resulted in selection of a wire with a 10 mil insulation wall weighing 3.72 pounds per 1000 feet. A protective jacket was used to encapsulate the harness to protect the thin wall insulated wire and this configuration became known as a "compact" harness and was used in over 4200 F-4's. By 1966, as the F-4 expanded its avionics capabilities, more and more wire was crowded in the "compact" harness and the interconnect harnesses were again becoming difficult to install and maintain. This led to the development in 1968 of a 7 mil, 1.5 pound per

1000 feet "minicomp" harness which was utilized on several flight test aircraft. Despite these efforts to reduce the size and volume of the interconnect system, F-4 avionics growth during the Viet Nam War necessitated the use of external waveguides for some equipment, because there wasn't any space left within the airframe. The above trends and factors have prompted the investigation of new designs and new technologies for aircraft interconnect systems.

The purpose of the A-7 ALOFT economic analysis is to evaluate two alternative interconnect technologies, coaxial cable and fiber optics, which when combined with data multiplexing have the potential to significantly reduce the weight and volume of today's systems and satisfy the projected data rate requirements of tomorrow's systems. In addition, fiber optic technology promises to reduce or eliminate current avionic system electrical problems such as electromagnetic interference (EMI), cross talk, short circuits, ringing, and electro-magnetic pulse (EMP) susceptability while enhancing safety and reducing vulnerability through elimination of spark hazards and damage overloads. It should be noted that the major advantages of fiber optics, in the data transfer application, are indeed based on disadvantages found in today's wire systems.

The A-7 ALOFT cost estimating problem is to develop appropriate life cycle costs of the alternative coaxial cable and fiber optic interconnect systems to assist in making the development decision on a cost benefit tradeoff basis. Since costs which are the same for either alternative will not add information to such a comparison, they will be eliminated. The resultant costs, differential costs, differ between the

two alternatives and are utilized to concentrate the analysis and decision making on the relevant cost categories. The specification of differential life cycle costs limits the cost estimating problem to the essentials. This is particularly important to this study, due to the time allowed, the conceptual stage of the A-7 ALOFT effort, and the uncertainties found in any new development, technology, or infant industry.

D. THE ANALYTICAL APPROACH

The analytical approach is quite simple: (1) determine what must be costed, and (2) develop the means to specify such costs in the case of fiber optics. To do this an extensive literature search of life cycle costing and fiber optic technology was conducted utilizing the services of the Defense Documentation Center, Defense Logistics Studies Information Exchange, and Naval Postgraduate School Library.

The purpose of the initial literature search and review was to determine the availability of previous work in this area, gain insight and knowledge of the technologies, avoid duplication of past efforts, and benefit from past lessons learned. Upon completion of this review it was clear that dispite the emphasis and extensive work in both life cycle costing and fiber optic fields that:

(1) the economic aspect of fiber optic technology has not been addressed except in recent NELC/NPS efforts,

(2) That with few exception, LCC models and methodology (especially in aircraft area) are addressed to the system vice subsystem levels of aggregation,

(3) that this may be the first attempt to develop and specify a LCC model for an aircraft internal data transmission system. This preliminary conclusion is supported by further investigation of electrical system cost estimating techniques discussed in Chapter IV.

In view of the above findings it was concluded that an A-7 ALOFT LCC model would need to be developed from scratch. Such a model, or any LCC model, must be structured to support its intended use, and recognize such factors as the state of project development, technology, availability/unavailability of data, and accuracy of results. In addition, the model format should be selected to take advantage of existing data bases and support future costing efforts which may be required. Above all, and in view of the conceptual nature of this project, the analysis should be explicit, the assumptions specified, and the costing relationships identified for ease of future reference and updating. In view of these combined requirements the authors have developed a step-by-step, element-by-element analysis of the applicalbe A-7 ALOFT cost elements in Chapter II.

As indicated in the DoD Life Cycle Costing Guide for System Acquisitions the Total Life Cycle cost of a system may be thought of in terms of two parts:

$LCC_T = LCC_D + LCC_E$, where

LCC_T = total life cycle cost

LCC_D = that portion of LCC_T which is relevant to the decision under consideration

LCC_E = that portion of LCC_T which is excluded in reaching the specific decision.

Chapter II identifies the excluded (LCC_E) elements, the total (LCC_T) life cycle cost elements, and the applicable differential (LCC_D) life-cycle cost elements of the fiber optic/coaxial cable alternatives. The differential life cycle costs (LCC_D) represents those life cycle costs which should differ between the two alternatives and are therefore relevant for the desired comparison; while those excluded life-cycle costs (LCC_E) are the same for each alternative. This process limits and directs the analysis to those cost elements which are not identical in order to compare the alternatives, while still identifying total life cycle cost elements which may be needed for budgetary purposes later in the development.

The next analysis step is to develop the costing methodology or means to specify the LCC_D cost elements. In Chapter III, the authors restructure the LCC_D model defined in Chapter II on an element-by-element basis with the basic substitution:

$C^*_{Fo} = A\, C_{cc}$, where

C^*_{Fo} is the cost of the fiber optic alternate for the LCC_D element,

C_{cc} is the cost of the coaxial cable alternative for the same LCC_D element, and

$A = \frac{C^*_{Fo}}{C_{cc}}$ represents the relative cost of the fiber optic alternative as a percentage of the coaxial cable cost.

The purpose of this transformation is to facilitate a direct comparison of model cost elements, at any level of aggregation, structure a supporting Delphi analysis, and better identify cost element estimating uncertainty.

The above procedure was developed from the following reasoning. Comparitive LCC_D cost elements represent the cost of performing an identical function or a similar effort in different technologies. It seems logical when comparisons of new versus mature technologies are conducted, that the estimates of LCC_D costs for a mature technology with previous cost applications will be more reliable and more readily determined then a similar estimate for a new technology. Intitively, it also seems reasonable, that an expert in the mature technology can better assess comparitive rather than absolute questions concerning the new technology. For example, in the A-7 ALOFT analysis, an aircraft electrical system designer familiar with coaxial cable applications might better address a compartive question such as: "Given the characteristics of fiber optics, would it take you more or less time to design this coaxial circuit using fiber optics? How much more? Twice as much? Half as much?" rather than, "How long would it take you to design this circuit using fiber optic cable?" The authors have constructed a matrix of the advantages/disadvantages of the fiber optic and coaxial cable alternatives and their probable general affect (see Table I) on each aggregate cost element to estimate the ratio of fiber optic to coaxial cable cost.

Analyst disagreement on the proper limits to assign, helps to identify those cost elements where greater uncertainty exists or additional background is required. In any event, such an analysis can help structure the problem, provide an initial estimate to evaluate identical costs established by different techniques, and structure a Delphi analysis.

In Chapter IV, the analysis turns to the investigation and evaluation of alternative techniques for developing costing methodology for each LCC_D cost element. This effort consists of an initial review of existing LCC models to identify the applicability of a published costing relationship for this application. Then, the feasibility, applicability, and availability of various cost estimating techniques (cost estimating relationship, engineering methods, analogy, and Delphi methods) are considered for each element for which a previous relationship does not exist and an appropriate costing methodology established. Chapter IV concludes with an input analysis to determine the requirement for subsequent tests or data collection which may be needed to exercise the model, and the explicit specification of the A-7 ALOFT LCC_D cost model developed.

Summary study results, considerations, findings and recommendations complete this phase of the A-7 ALOFT ecomonic analysis.

equipment procurement, new facilities, production installation, initial spares and support equipment such as test instrumentation.

OPERATING costs are the recurring program element costs required to operate and maintain the capability as well as the costs associated with introducing improvement(s) to extend the equipment service life. Operating costs include those costs for personnel pay and allowances, equipment maintenance, training, logistics support and consumables.

DISPOSAL costs are usually considered to be the costs associated with retiring the equipment from the inventory, at the end of its economic life, minus any residual or scrap value this equipment may have left at that time. Often the two costs are assumed equal so that they cancel each other, making a net contribution of zero to the total life cycle cost.

Differential life cycle costs of an equipment or system are the relevant life cycle costs which must be evaluated when a comparison between alternative equipments or systems is desired. Development, Acquisition, Operating and Disposal costs are considered within the concept of differential life cycle costs but as explained earlier, the disposal cost for this analysis was set equal to zero.

Effective cost analysis requires that all costs associated with a system be identified and classified according to their applicability to the particular cost model of concern. The authors intent is to identify all cost elements and with the

II. COST ELEMENT IDENTIFICATION AND LIFE CYCLE COST MODEL DEVELOPMENT PROCESS

A. PURPOSE

The purpose of this chapter is to identify and to classify cost elements according to their individual applicability to specific cost models. After cost elements have been identified and classified, two cost models will be developed; the TOTAL LIFE CYCLE COST MODEL and the DIFFERENTIAL LIFE CYCLE COST MODEL.

Total life cycle cost of an equipment or system is the total cost, to the government, of acquisition and ownership of that equipment or system over its full economic life. It includes development, acquisition, operating and, where applicable, disposal costs.

DEVELOPMENT costs are those program costs primarily associated with the development of a new or improved capability to the point where it is ready for procurement and operational use. Development costs commonly include costs for initial research and development of the equipment, prototype procurement and installation, test and evaluation and the management and support necessary to accomplish those tasks.

ACQUISITION costs are those program costs required beyond development to introduce into operational use a new capability, or to procure initial, additional or replacement equipment for operating forces. Acquisition costs include

use of a standard format systematically classify each identified cost element. Figure 2-II-1 represents the standard analysis format developed for this purpose, the use of which is described later in this chapter.

The determination concerning a specific cost elements applicability to one of the cost models is of course judgemental. This is not considered a problem since all cost elements have been identified and the future inclusion or exclusion of any specific element can be accomplished as the economic analysis progresses. Flexibility and universality are key features of this type approach to a cost analysis problem.

B. ASSUMPTIONS

Assumptions pertinent to the analytical development of the model are specified for reference below. Use of these assumptions within the analysis have been keyed to the specified paragraph.

(1) One contractor will develop, produce and install either the fiber optic or coaxial cable interconnect system. This assumption enables a comparison of all program/contract factors on an equal basis to minimize contractor induced cost differences on the outcome, e.g., overhead rates, G & A costs, etc., will be developed identically for either alternative.

(2) The inherent qualities of an equipment or system using fiber optic echnology eliminates the requirement for on-site (after production) contractor support of the equipment

Cost element symbol
(from Figure 2-II-8)

(Major cost category)

(Hierarchy of cost breakdown structure)

(Cost element of concern)

Applicable cost model(s) identified, (if checked)	( ) Total
	( ) Differential
Cost element excluded from both models (if checked)	( ) Excluded

NOTE: Both Total and Differential may be checked.

DESCRIPTION

Brief description of this cost element

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Reason for either including this cost element in the total and/or differential cost model(s) or excluding this cost element from either or both model(s). This section will substantiate the appropriateness of the box(es) checked above.

Standard Analysis Format.

Figure 2-II-1

or system. This does not apply to any future modifications or field changes which might require contractor engineering assistance.

(3) Maintenance required on coaxial cable is presently performed by Aviation Electricians and/or Aviation Electronic Technicians. The coax maintenance skill training is already an integral part of formal Navy schools and will not need to be expanded to support A-7 ALOFT coaxial system requirements.

(4) The initial maintenance training sessions for fiber optics will be conducted by the contractor. During the initial sessions, both Navy maintenance personnel and future Navy instructors will be trained. The future instructors would already be teaching in the appropriate Navy school(s) and, therefore, could be given temporary additional duty as students of fiber optic equipment or system maintenance.

(5) A throw-away vice repair policy is assumed for both fiber optic drivers and receivers, based on present discrete component costs and reliability, interface module development, and anticipated technological advances.

(6) The characteristics of fiber optic cable and components cause it to be more reliable and maintenance free than its coax cable counterpart. Reliability and maintainability data will be collected during the A-7 ALOFT program demonstration phase to test the validity of this assumption.

(7) System disposal cost equals zero. This cost is not relevant since both the current and the proposed systems have a physical life expectancy greater than the 10-year life cycle assumed.

(8) The basic technical factors and model assumptions outlined in NELC Technical Document 435 will apply. Specifically:

(a) The baseline configuration consists of signals listed in the A-7 ALOFT Signal List. (NELC TD 435, Appendix B.)

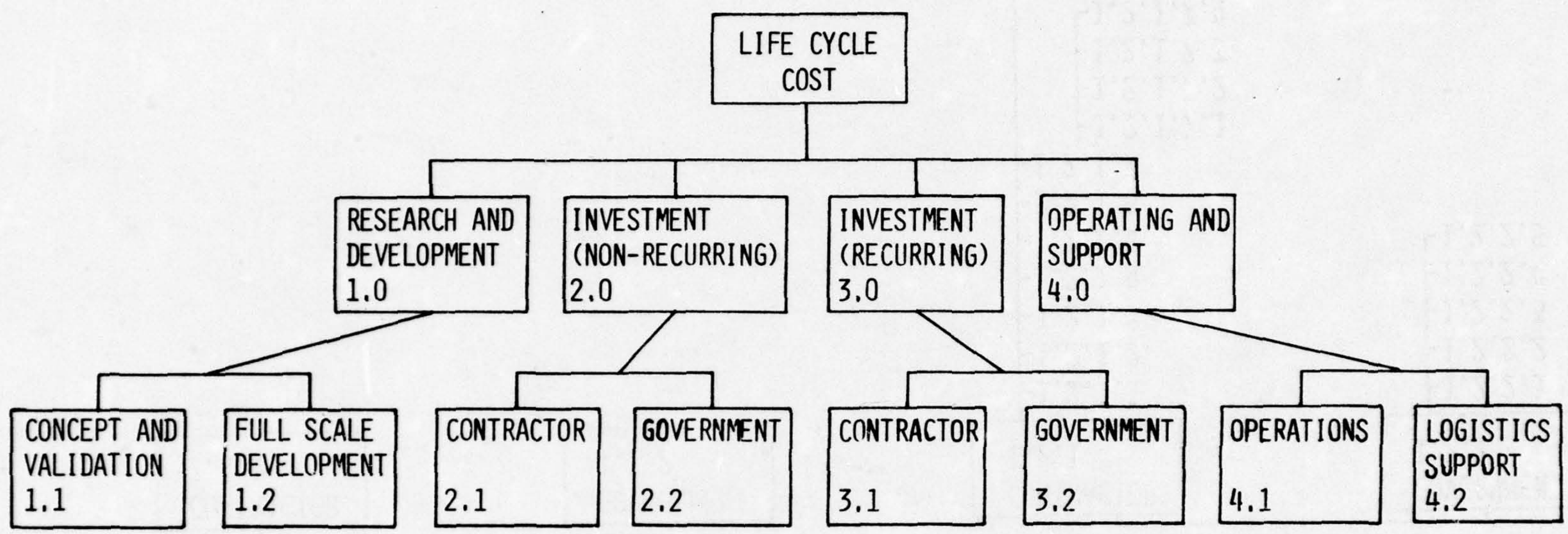
(b) The existence of the necessary multiplexing system for each alternative is assumed.

(c) Ten (10) year life cycle costs commencing in FY 1977 will be calculated.

C. IDENTIFICATION AND DEVELOPMENT METHODOLOGY

A convenient and thorough method to identify cost elements is to associate them with specific work elements which they represent. Normally this would be done with the use of a work breakdown structure(28), but aircraft wiring tasks are not broken down into that standard structure. Aircraft wiring tasks are primarily aggregated at the airframe level of a breakdown structure. Because there was no cost data available within the existing standard work breakdown structure the authors used the second level cost breakdown structure shown in Figure 2-II-2. This cost breakdown structure is further sub-divided into lower levels as shown in Figures 2-II-3, 2-II-4, 2-II-5, and 2-II-6.

The procedural flow of this cost model development is diagrammed in Figure 2-II-7 and is the primary structure for the remainder of this chapter. Phase three of the model development flow chart will be conducted as time permits, but a detailed examination of this phase will be reserved for a future project.



COST BREAKDOWN STRUCTURE

FIGURE 2-II-2

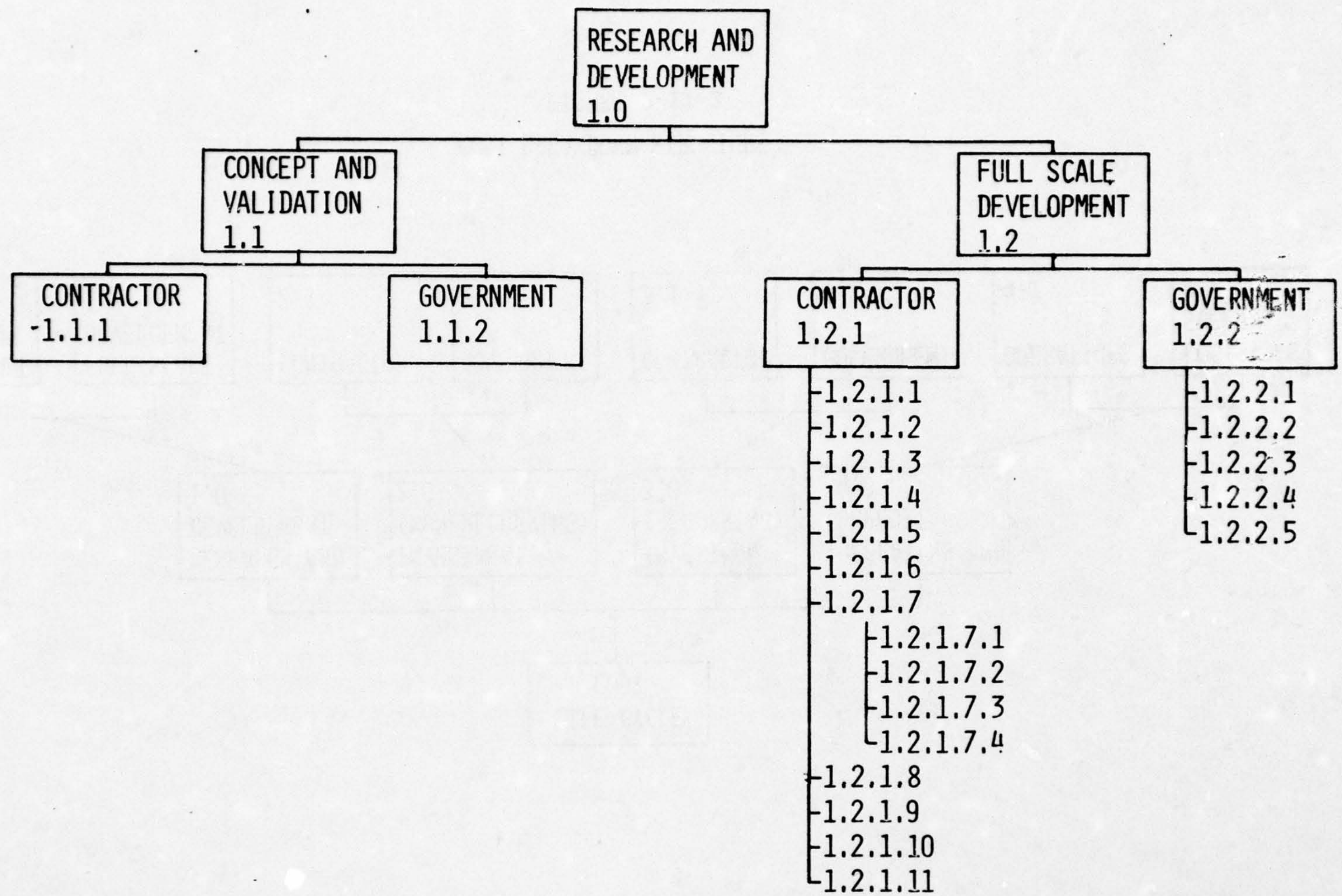
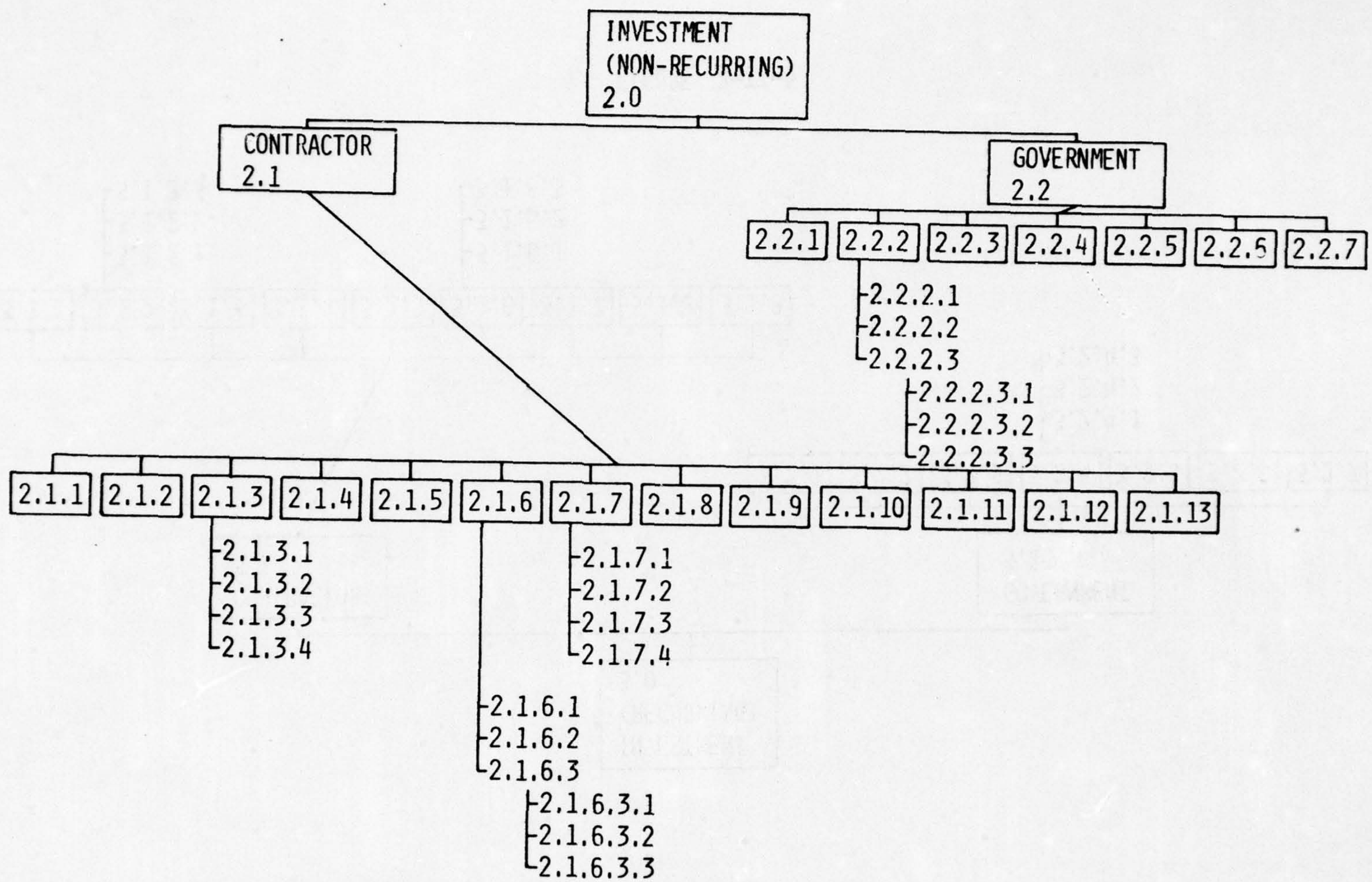

RESEARCH AND DEVELOPMENT 1.0
CONCEPT AND VALIDATION 1.1
CONTRACTOR 1.1.1
GOVERNMENT 1.1.2
FULL SCALE DEVELOPMENT 1.2
CONTRACTOR 1.2.1
1.2.1.1
1.2.1.2
1.2.1.3
1.2.1.4
1.2.1.5
1.2.1.6
1.2.1.7
1.2.1.7.1
1.2.1.7.2
1.2.1.7.3
1.2.1.7.4
1.2.1.8
1.2.1.9
1.2.1.10
1.2.1.11
GOVERNMENT 1.2.2
1.2.2.1
1.2.2.2
1.2.2.3
1.2.2.4
1.2.2.5

FIGURE 2-II-3



INVESTMENT
(NON-RECURRING)
2.0
CONTRACTOR
2.1
GOVERNMENT
2.2
2.2.1
2.2.2
2.2.3
2.2.4
2.2.5
2.2.6
2.2.7
2.2.2.1
2.2.2.2
2.2.2.3
2.2.2.3.1
2.2.2.3.2
2.2.2.3.3
2.1.1
2.1.2
2.1.3
2.1.4
2.1.5
2.1.6
2.1.7
2.1.8
2.1.9
2.1.10
2.1.11
2.1.12
2.1.13
2.1.3.1
2.1.3.2
2.1.3.3
2.1.3.4
2.1.7.1
2.1.7.2
2.1.7.3
2.1.7.4
2.1.6.1
2.1.6.2
2.1.6.3
2.1.6.3.1
2.1.6.3.2
2.1.6.3.3

FIGURE 2-II-4

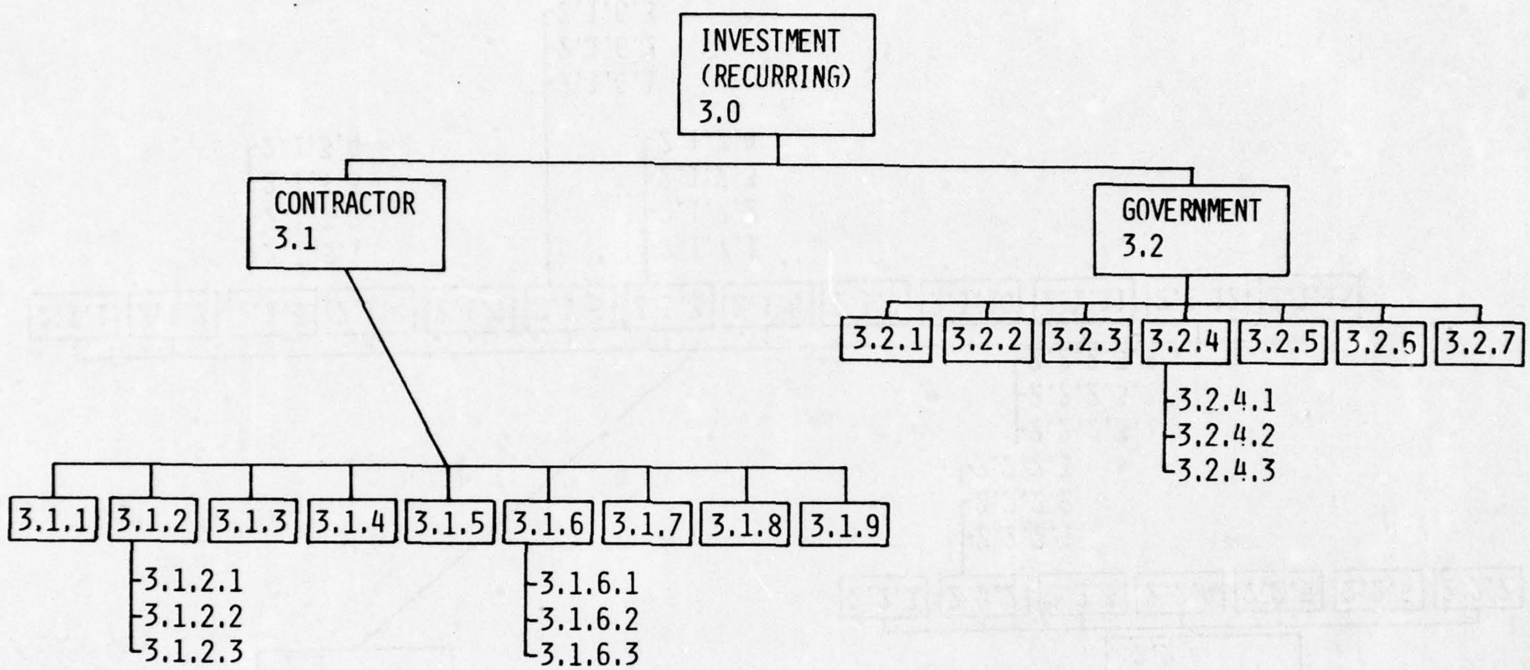

INVESTMENT
(RECURRING)
3.0
CONTRACTOR
3.1
GOVERNMENT
3.2
3.1.1
3.1.2
3.1.3
3.1.4
3.1.5
3.1.6
3.1.7
3.1.8
3.1.9
3.1.2.1
3.1.2.2
3.1.2.3
3.1.6.1
3.1.6.2
3.1.6.3
3.2.1
3.2.2
3.2.3
3.2.4
3.2.5
3.2.6
3.2.7
3.2.4.1
3.2.4.2
3.2.4.3

FIGURE 2-II-5

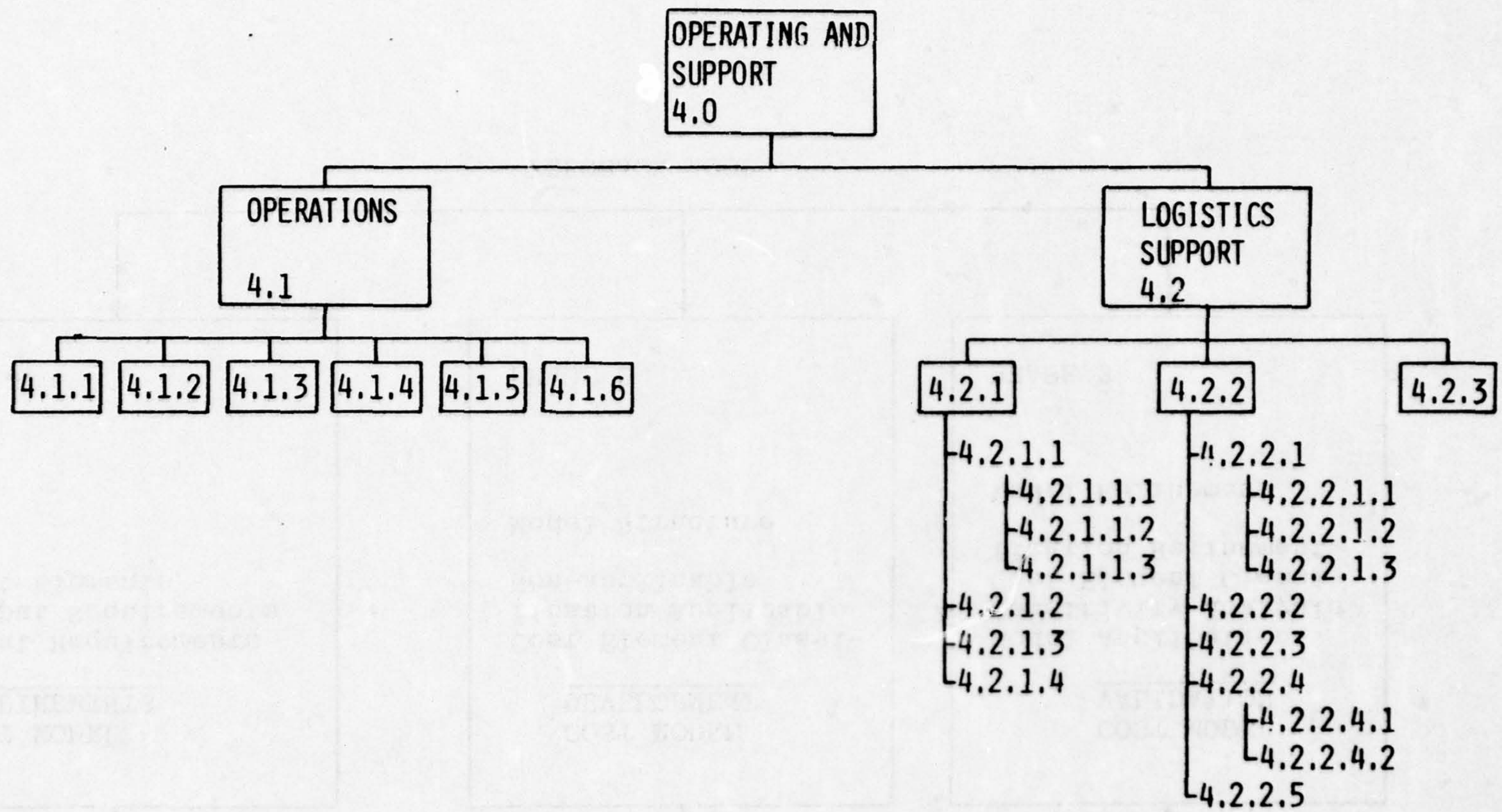
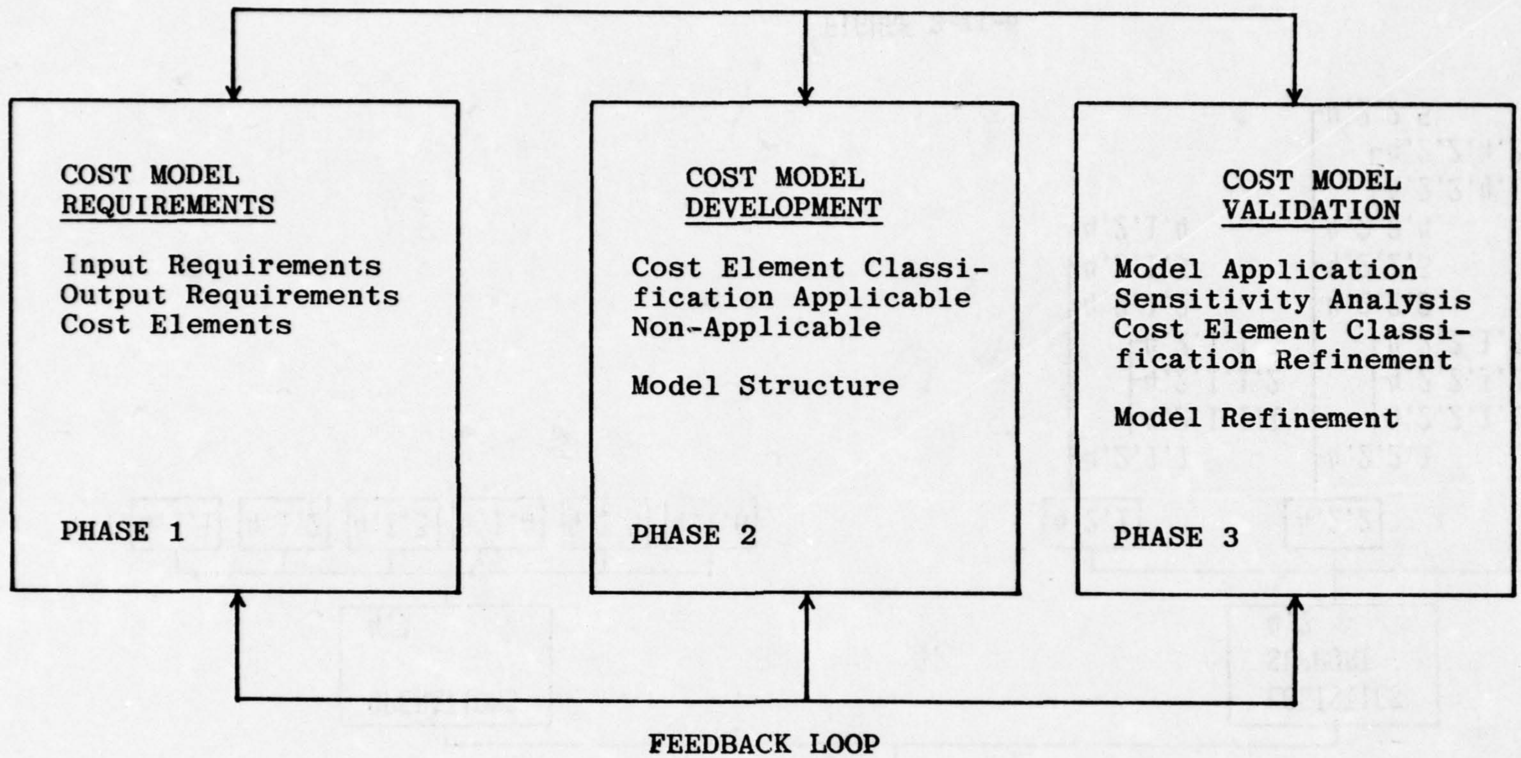

OPERATING AND SUPPORT 4.0
OPERATIONS 4.1
LOGISTICS SUPPORT 4.2
4.1.1
4.1.2
4.1.3
4.1.4
4.1.5
4.1.6
4.2.1
4.2.2
4.2.3
4.2.1.1
4.2.1.1.1
4.2.1.1.2
4.2.1.1.3
4.2.1.2
4.2.1.3
4.2.1.4
4.2.2.1
4.2.2.1.1
4.2.2.1.2
4.2.2.1.3
4.2.2.2
4.2.2.3
4.2.2.4
4.2.2.4.1
4.2.2.4.2
4.2.2.5

FIGURE 2-II-6



A-7 ALOFT Cost Model Development

Figure 2-II-7

1. Cost Model Input Structure

A cost model can be developed for any combination of several reasons; to aid in the decision process of a trade-off analysis, to help develop the guidelines for a program budget, to assist in the determination of the cost effectiveness of a proposed engineering change to an equipment or system, to list only a few. Because of the different reasons for which cost models are developed and the different aggregations of cost data available, cost models must be individually structured to best meet the purpose for which they are intended.

In order to structure the results of this anlaysis effort and ensure compatability with future needs of fiber optic cost analysis programs and data availability, the cost model was developed using four interrelated input components. The four input components are:

(1) descriptive information on assumptions setting forth such items as performance or physical characteristics, operational/maintenance concepts, and the like.

(2) an input structure containing well-defined categories identified within the "Cost Effectiveness Program Plan for Joint Tactical Communication."(55)

(3) Cost estimating relationships or estimating procedures for each element in the input structure.

(4) a systematic, sequential process to reduce all elements in the input structure to a minimal number of relevant elements.

Using the four structured input components, two cost models were developed and defined as:

Total Life Cycle Cost model which associates all applicable cost elements over the life time of an equipment or system. This model would, by necessity, be large and possibly difficult to evaluate. It is the sum of all applicable cost elements in the four major cost categories;

Research and development costs,
Investment (non-recurring) costs,
Investment (recurring) costs,
Operating and support costs.

Differential Life Cycle Cost model which compares the differential costs between two similar cost elements of two different equipments or systems, Since this model only operates with differential costs, it can be used when a detailed comparison between two equipments or systems is required. This model is the sum of differential costs identified with a small number of applicable cost elements in the four major cost categories listed above.

Within each cost model are four major cost categories which have been defined as:

Research and Development costs refer to all costs associated with the research, development, test and evaluation of the system or equipment. This normally includes all costs during concept initiation, validation and full scale development.

Investment (non-recurring) costs refer to those costs incurred beyond the program development phase, which are one time costs incurred during the program production phase. These costs can recur if there is a change in design, contractor or manufacturing process.

Investment (recurring) costs include those production costs that recur with each unit produced. These costs tend to be subject to a learning curve concept in which the cost per unit decreases as quantity increases.

Operating and Support costs is normally the largest category. It includes the costs of personnel, material, facilities and other costs required to operate, maintain and support a system or equipment during its useful life time.

2. Cost Model Development

The total system life cycle cost structure is subdivided into lower level cost elements taken from the "Cost Effectiveness Program Plan for Joint Tactical Communications" (TRI-TAC)(55) and presented in Figure 2-II-8. After a detailed literature search, the TRI-TAC document was chosen as the source of cost elements because of its completeness and conformity with DoD Instruction 7041.3.(27) When specific cost elements are identified as applicable, they comprise the basis of the life cycle cost model. It is doubtful that all cost elements are applicable to any specific cost model, therefore each cost element must be systematically examined and its applicability to a specific cost model determined.

Each cost element listed in Figure 2-II-8 has been systematically examined by using the decision process outlined in Figure 2-II-9. The results of this detailed analysis is found in Appendix J in the form of the standard analysis format shown in Figure 2-II-1. If future analysis requirements dictate a change to the cost model, individual elements requiring change can be reevaluated without a full investigation of all cost elements. Figure 2-II-1 explains the various sections of the standard analysis format as used throughout this analysis.

Those cost elements classified as applicable to the TOTAL LIFE CYCLE COST model are structured in Figure 2-II-10

1.0 Research and Development
    1.1 Concept and Validation
        1.1.1 Contractor
            1.1.2 Government
    1.2 Full Scale Development (FSD)
        1.2.1 Contractor
            1.2.1.1 Program Management
            1.2.1.2 Engineering
            1.2.1.3 Fabication
            1.2.1.4 Contractor Development Tests (CDT)
            1.2.1.5 Test Support
            1.2.1.6 Producibility Engineering and Planning (PEP)
            1.2.1.7 Data
                1.2.1.7.1 Engineering Data
                1.2.1.7.2 Support Data
                1.2.1.7.3 Management Data
                1.2.1.7.4 Technical Orders and Manuals
            1.2.1.8 Peculiar Support and Test Equipment
            1.2.1.9 Other
            1.2.1.10 General and Administrative
            1.2.1.11 Fee
        1.2.2 Government
            1.2.2.1 Program Management
            1.2.2.2 Test Site Activation
            1.2.2.3 Government Tests (DTE/IOTE)
            1.2.2.4 Government Furnished Equipment (GFE)
            1.2.2.5 Other

COST ELEMENT STRUCTURE

Source: TRI-TAC

Figure 2-II-8

2.0 Investment (Non-Recurring)

2.1 Contractor

2.1.1 Program Management

2.1.2 Producibility Engineering and Planning (PEP)

2.1.3 Initial Production Facilities (IPF)

2.1.3.1 Production Engineering

2.1.3.2 Tooling

2.1.3.3 Industrial Facilities

2.1.3.4 Manufacturing Support Equipment

2.1.4 Technical Support

2.1.5 Initial Spares and Repair Parts

2.1.6 Initial Training

2.1.6.1 Training Facilities

2.1.6.2 Training Devices and Equipment

2.1.6.3 Initial Student Training

2.1.6.3.1 Operator Training

2.1.6.3.2 Maintenance Training

2.1.6.3.3 Instructor Training

2.1.7 Data

2.1.7.1 Engineering Data

2.1.7.2 Support Data

2.1.7.3 Management Data

2.1.7.4 Technical Orders and Manuals

2.1.8 Leaseholds

2.1.9 Common Support Equipment

2.1.10 Peculiar Support and Test Equipment

2.1.11 Other Non-Recurring Costs

2.1.12 General and Administrative

2.1.13 Fee or Profit

Figure 2-II-8 (continued)

2.2 Government (Non-Recurring)

2.2.1 Program Management

2.2.2 Initial Training

2.2.2.1 Training Facilities

2.2.2.2 Training Devices and Equipment

2.2.2.3 Initial Student Training

2.2.2.3.1 Operator Training

2.2.2.3.2 Maintenance Training

2.2.2.3.3 Instructor Training

2.2.3 Production Acceptance Test and Evaluation (PATE)

2.2.4 Operational Test and Evaluation (OTE)

2.2.5 Test Site Activation

2.2.6 Government Furnished Equipment (GFE)

2.2.7 Other Non-Recurring Investment Costs

Figure 2-II-8 (continued)

3.0 Investment (Recurring)

3.1 Contractor

3.1.1 Manufacturing

3.1.2 Production Material

3.1.2.1 Purchased Equipment and Parts

3.1.2.2 Subcontracted Items

3.1.2.3 Other Material

3.1.3 Sustaining Engineering

3.1.4 Quality Control and Inspection

3.1.5 Packaging and Transportation

3.1.6 Operational/Site Activation

3.1.6.1 Site Construction

3.1.6.2 Site/Ship/Vehicle Conversion

3.1.6.3 Assembly, Installation and Checkout

3.1.7 Other Recurring Investment Costs

3.1.8 General and Administrative Costs

3.1.9 Fee or Profit

3.2 Government (Recurring)

3.2.1 Quality Control and Inspection

3.2.2 Sustaining Engineering

3.2.3 Transportation

3.2.4 Operational/Site Activation

3.2.4.1 Site Construction

3.2.4.2 Site/Ship/Vehicle Conversion

3.2.4.3 Assembly, Installation and Checkout

3.2.5 Technical Orders and Manuals

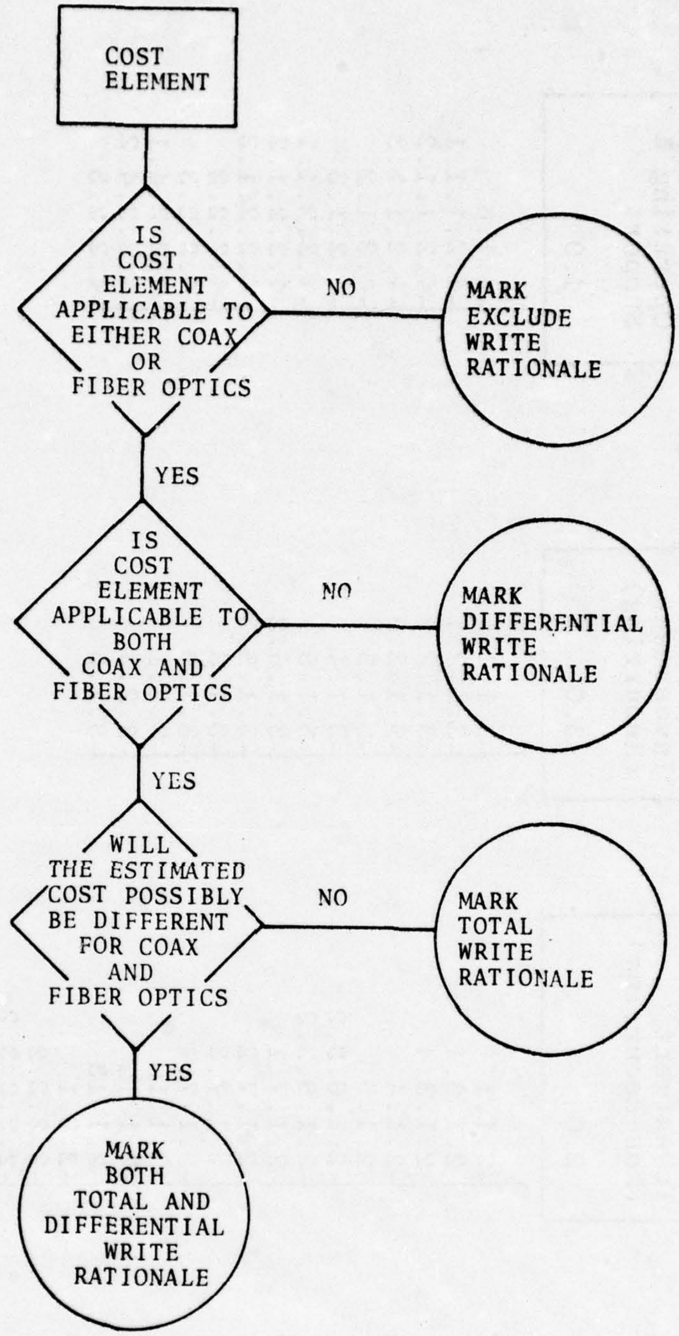
3.2.6 Government Furnished Material

3.2.7 Other Recurring Cost

Figure 2-II-8 (continued)

4.0 Operating and Support Costs (O&S)
  4.1 Operations
    4.1.1 Electrical Power
    4.1.2 Special Materials
    4.1.3 Operator Personnel
    4.1.4 Operational Facilities
    4.1.5 Equipment Leaseholds
    4.1.6 Other Operations Costs
  4.2 Logistic Support
    4.2.1 Maintenance
      4.2.1.1 Personnel
        4.2.1.1.1 Organizational Maintenance Personnel
        4.2.1.1.2 Intermediate Maintenance Personnel
        4.2.1.1.3 Depot Maintenance Personnel
      4.2.1.2 Maintenance Facilities
      4.2.1.3 Support Equipment Maintenance
      4.2.1.4 Contractor Services
    4.2.2 Supply
      4.2.2.1 Personnel
        4.2.2.1.1 Organizational Supply Personnel
        4.2.2.1.2 Intermediate Supply Personnel
        4.2.2.1.3 Depot Supply Personnel
      4.2.2.2 Supply Facilities
      4.2.2.3 Spare Parts and Repair Material
      4.2.2.4 Inventory Administration
        4.2.2.4.1 Inventory Management
        4.2.2.4.2 Inventory Holding
      4.2.2.5 Transportation and Packaging
    4.2.3 Other Logistic Support Costs

Figure 2-II-8 (continued)



COST ELEMENT SELECTION DECISION PROCESS

FIGURE 2-II-9

- TOTAL LIFE CYCLE COST
  - Research & Development 1.0
    - 1.1.1
    - 1.1.2
    - 1.2.1.1
    - 1.2.1.2
    - 1.2.1.3
    - 1.2.1.4
    - 1.2.1.5
    - 1.2.1.6
    - 1.2.1.7.1
    - 1.2.1.7.2
    - 1.2.1.7.3
    - 1.2.1.7.4
    - 1.2.1.8
    - 1.2.1.10
    - 1.2.1.11
    - 1.2.2.1
    - 1.2.2.2
    - 1.2.2.3
  - Investment (Non-Recurring) 2.0
    - 2.1.1
    - 2.1.3.1
    - 2.1.3.4
    - 2.1.4
    - 2.1.5
    - 2.1.6.3.2
    - 2.1.6.3.3
    - 2.1.7.1
    - 2.1.7.2
    - 2.1.7.3
    - 2.1.7.4
    - 2.1.10
    - 2.1.12
    - 2.1.13
    - 2.2.1
    - 2.2.2.2
    - 2.2.2.3.2
    - 2.2.2.3.3
    - 2.2.3
  - Investment (Recurring) 3.0
    - 3.1.1
    - 3.1.2.1
    - 3.1.2.2
    - 3.1.2.3
    - 3.1.3
    - 3.1.4
    - 3.1.5
    - 3.1.6.2
    - 3.1.6.3
    - 3.1.8
    - 3.1.9
    - 3.2.1
    - 3.2.3
    - 3.2.5
  - Operating & Support 4.0
    - 4.1.6
    - 4.2.1.1.1
    - 4.2.1.1.2
    - 4.2.1.1.3
    - 4.2.1.2
    - 4.2.1.3
    - 4.2.2.1.1
    - 4.2.2.1.2
    - 4.2.2.1.3
    - 4.2.2.2
    - 4.2.2.3
    - 4.2.2.4.1
    - 4.2.2.4.2
    - 4.2.2.5

TOTAL LIFE CYCLE COST MODEL

Applicable Cost Elements Structured by Major Cost Category

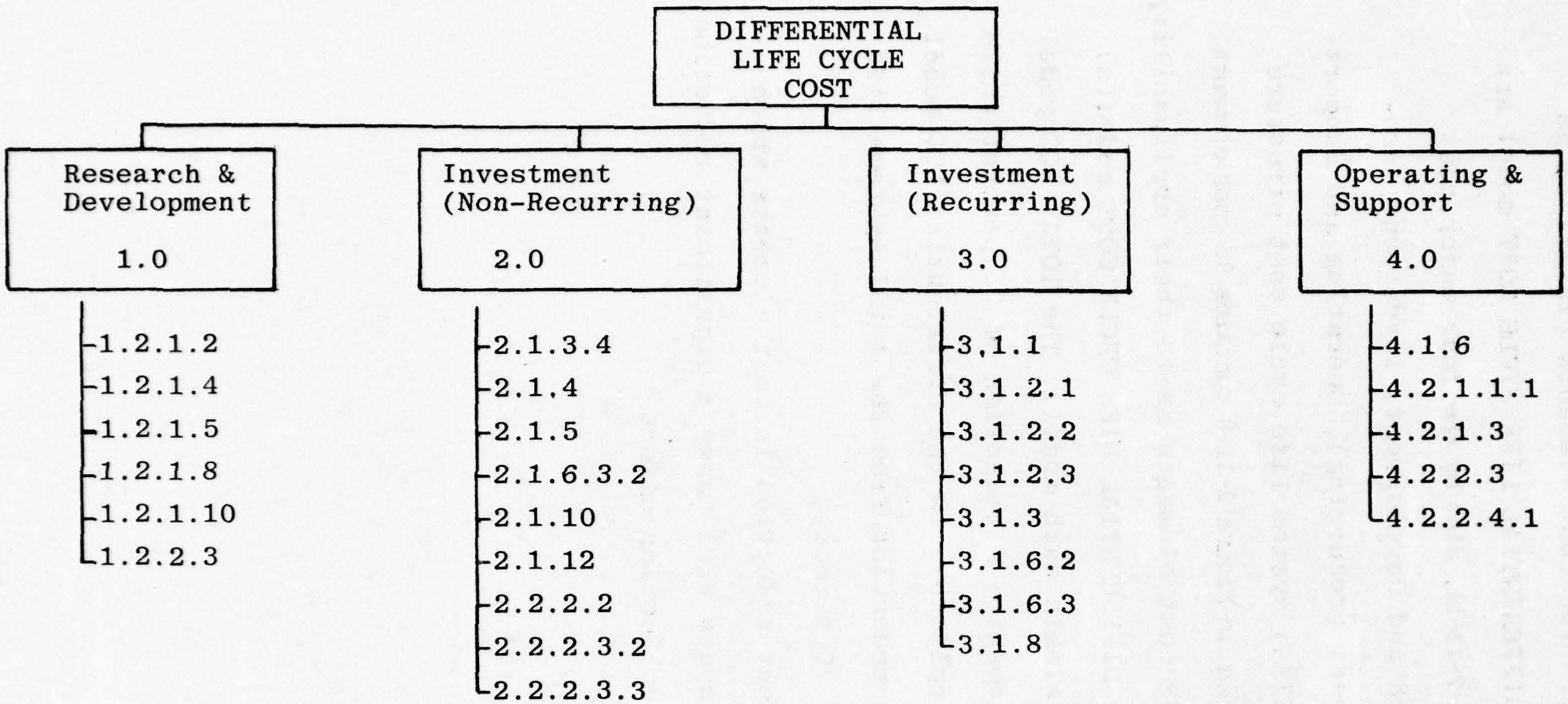
Figure 2-II-10

major cost category. The cost elements classified as applicable to the DIFFERENTIAL LIFE CYCLE COST model are structured in Figure 2-II-11, also by the four major cost categories; Research and Development, Investment (non-recurring), Investment (recurring), Operating and Support.

The TRI-TAC(55) system life cycle cost structure previously identified in Figure 2-II-8 contains 98 cost elements. Classifying those 98 cost elements as to their applicability to the TOTAL and/or DIFFERENTIAL LIFE CYCLE COST model(s) reduced the number within each model. The TOTAL LCC model retained 65 cost elements, a reduction of 35 percent while the cost elements applicable to the differential LCC model numbered only 28; a reduction from the total systems life cycle cost model of 70 percent.

The 70 percent reduction in cost elements which require cost data inputs will cause a significant reduction in the future data collection effort.

61.



DIFFERENTIAL LIFE CYCLE COST MODEL

Applicable Cost Elements Structured by Major Cost Category

Figure 2-II-11

III. FIBER OPTIC AND COAX COST ELEMENTS COMPARISON

A. PURPOSE

The purpose of Chapter III is to present a first approximation cost comparison between fiber optics and coaxial cable technology cost elements. Those cost elements previously identified and listed in Figure 2-II-11 were used for the cost comparison.

Comparing cost data for two different technologies, both performing the same function is a valid method of cost analysis. The authors have produced a cost comparison, on a cost element by element basis, between coax and fiber optic technologies. The basis for this comparison is the analogy method of cost estimating. The anology method relies upon persons knowledgeable in performing a task in one technology so that they can be questioned about the level of effort (in dollars, man-hours, etc.) required to perform the same task using a substitute technology.

This chapter presents a coax/fiber optic technology cost comparison based upon the authors best estimate or first approximation of cost estimates. Chapter IV expands upon this analogy cost estimating method with recommended procedures for cost data refinement.

Table I was developed as an aid to presenting the rationale for the author's first approximation of the costs presented in Table II. The performance characteristics of

FIBER OPTIC CHARACTERISTICS \ DIFFERENTIAL COST ELEMENTS	1.2.1.2	1.2.1.4	1.2.1.5	1.2.1.8	1.2.1.10	1.2.2.3	2.1.3.4	2.1.4	2.1.5	2.1.6.3.2	2.1.10	2.1.12	2.2.2.2	2.2.2.3.2	2.2.2.3.3	3.1.1	3.1.2.1	3.1.2.2	3.1.2.3	3.1.3	3.1.6.2	3.1.6.3	3.1.8	4.1.6	4.2.1.1.1	4.2.1.3	4.2.2.3	4.2.2.4.1
HIGH TEMPERATURE TOLERANCE	X																			X	X			X	X		X	
VIBRATION TOLERANCE	X																			X	X			X	X		X	
NO CROSS TALK	X	X	X			X		X												X	X							
RFI/EMI/NOISE IMMUNITY	X	X	X			X		X												X	X							
TOTAL ELECTRICAL ISOLATION	X																			X	X							
NO SPARK/FIRE HAZARD	X																			X	X			X	X			
NO SHORT CIRCUIT LOADING	X																			X	X			X	X			
EMP IMMUNITY	X	X	X			X		X												X	X							
NO CONTACT DISCONTINUITY	X									X			X	X	X					X	X			X	X			
WIDE SIGNAL BANDWIDTH	X									X			X	X	X					X	X							
CORROSION RESISTANT	X																			X	X			X	X		X	
HIGH SECURITY	X	X	X			X		X												X	X							
SMALL SIZE	X															X				X	X			X				
LIGHT WEIGHT	X															X				X	X			X				
REDUCED SAFETY HAZARD	X																			X	X			X	X		X	
REDUCED ELECTRICAL POWER REQUIREMENTS	X																			X	X			X				

FIBER OPTIC PERFORMANCE CHARACTERISTICS

TABLE I

RESEARCH AND DEVELOPMENT

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
1.2.1.2 Full Scale Development Contractor Engineering	1.0	*	Since fiber optics is an infant technology there will undoubtly be a large effort expended to develop the potential use for fiber optics. The scope of this effort will be dependent upon both Government and industrial support or interest in the technology.
1.2.1.4 Full Scale Development Contractor Development Test	1.0	*	In anticipation of maximum benefit from a fiber optic Research and Development program, the contractor must conduct an exhaustive test program. This type of effort, properly conducted, has a historically high cost.
1.2.1.5 Full Scale Development Contractor Test Support	1.0	*	This cost will be highier for fiber optic for the same reasons as noted in cost element 1.2.1.4. Test support will be in conjunction with the effort identified in cost element 1.2.2.3.

COST ELEMENT COMPARISON

Table II

Table II (continued)

RESEARCH AND DEVELOPMENT

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
1.2.1.8 Full Scale Development Contractor Peculiar support and Test Equipment	1.0	2.0	Research and Development of peculiar support and test equipment is not expected to be a major effort. The anticipated requirements for support and test equipment that are unique or peculiar to the new fiber optic technology should be minimal.
1.2.1.10 Full Scale Development Contractor General and Administrative	1.0	1.8	The level of effort of Research and Development in the fiber optic technology is expected to be larger than a coax technology program. There is existing a data base for coax technology but the data base for fiber optic technology is only being developed at this time.
1.2.2.3 Full Scale Development Government Test	1.0	*	The culmination of an extensive Research and Development program are the purposeful tests. Expectations for future use of fiber optic technology dictates a major test and evaluation program. This effort will be much in excess of test programs for coax cable.
		*	During the Research and Development phase of a new program the ceiling cost is primarily limited by the funding available. The present interest in fiber optic technology is quite strong and the program is expected to grow rapidly.

Table II (continued)

INVESTMENT (NON-RECURRING)

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
2.1.3.4 Contractor Manufacturing Support Equipment	1.2	1.8	Manufacturing equipment for use with coax cable presently exists. To establish the capability of working with fiber optic cable, new support equipment will be required. This additional capability will cause an increase in the fiber optic support equipment cost.
2.1.4 Contractor Technical Support	0.6	1.0	The replacement of coax cable with fiber optic cable will be contingent upon several factors. One primary consideration will be successful testing during the Research and Development phase of a program. If fiber optic cable is used in aircraft production it will only be after successful early testing and the assumption is then made that follow-on testing will be minimized or possibly eliminated.
2.1.5 Contractor Initial Spare and Repair Parts	0.8	1.6	The advances in the fiber optic state-of-the-art and the ability of industry to economically mass produce cable, transmitter module and receives modules control this cost element range.

Table II (continued)

INVESTMENT (NON-RECURRING)

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
2.1.6.3.2 Contractor Initial Maintenance Training	1.2	2.0	Maintenance training for fiber optic equipment or systems will be in excess of the training presently conducted on systems using coax cable. The excess cost exists because a maintenance technician would be knowledgeable in coax cable maintenance but fiber optic technology is a new requirement in addition to this present ability.
2.1.10 Contractor Peculiar Support and Test Equipment	1.2	1.8	Maintenance and support equipment unique or peculiar to an equipment or system using fiber optic cable will be required. This requirement is in addition to the existing requirement for coax cable maintenance and support equipment already in use.
2.1.12 Contractor General and Administrative	0.9	1.0	Fiber optic technology should cause a production effort to be less than a simular coax system. Therefore, the General and Administrative costs would be slightly less for production using fiber optic technology.

Table II (continued)

INVESTMENT (NON-RECURRING)

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
2.2.2.2 Government Training Devices and Equipment	2.0	3.5	The knowledge of coax cable technology exists within the appropriate Navy schools today. Adding fiber optic technology to the existing school curriculum will generate a cost that is in excess of any cost associated with coax cable training.
2.2.2.3.2 Government Initial Maintenance Training	1.1	1.8	The Government cost to train both maintenance personnel (cost element 2.2.2.3.2) and instructor personnel (cost element 2.2.2.3.3) is directly related to the length of time required for the training. Fiber optic technology with require training in excess of that required presently by coax cable technology.
2.2.2.3.3 Government Initial Instructor Training	1.1	1.8	

Table II (continued)

INVESTMENT (RECURRING)

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
3.1.1 Contractor Manufacturing	0.8	2.0	As fiber optic technology advances and additional applications are discovered, the cost of material will probably decline. However, at this point in time the production base for fiber optics is limited, thereby keeping the cost of fiber optics above the cost of coax.
3.1.2.1 Contractor Production Purchased Equipment and Parts	0.8	2.0	Large quantity usage and mass production is expected to reduce the cost of fiber optic components to a level below that of simular coax components. The present demand for fiber optics is limited, therefore the cost of components is higher than coax.
3.1.2.2 Contractor Production Subcontracted Items	0.8	2.0	Increased applications of fiber optic technology coupled with a greater usage demand should reduce the cost of fiber optic components. At some point in future time, it is expected that fiber optic components will cost less than their coax counterparts but presently fiber optic component costs are generally higher than coax.

Table II (continued)

INVESTMENT (RECURRING)

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
3.1.2.3 Contractor Other Production Material	0.8	2.0	Raw material for the manufacture of fiber optic cable is readily available and mass production should decrease the cost of fiber optic components. Mass production can not begin until the demand for fiber optic increases. Copper is becoming a scarse commodity and therefore the cost of coax is expected to increase in the future.
3.1.3 Contractor Sustaining Engineering	0.7	0.9	The engineering costs associated with future modification or field changes of a fiber optic equipment or system will be less than those costs associated with a coax system. The use of fiber optic technology would place fewer restriction on design engineers.
3.1.6.2 Contractor Site/Ship/Vehicle Conversion	0.7	1.0	The physical characteristics of fiber optic cable allow its installation in places not accessible with coax cable. This attribute will allow design engineers to design fiber optic cable routes at a lower cost than coax cable.

Table II (continued)

INVESTMENT (RECURRING)

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
3,1,6.3 Contractor Operational Assembly, Installation, Checkout	0.85	1.0	In conjunction with the reduced cable route design conplexity, checkout will be simplified for fiber optic cable systems.
3.1.8 Contractor General and Administrative	0.9	1.0	Fiber optic technology should cause a production effort to be less than a simular coax system. Therefore, the General and Administrative costs would be slightly less for production using fiber optic technology.

Table II (continued)

OPPERATING AND SUPPORT

Cost Element	Fiber Optic Cost Minimum	Maximum	Remarks
4.1.6 Government Opportunity Cost	1.0	1.0	Reliability of a fiber optic cable system is expected to be higher than a simular coax system. If this assumption is valid, then the down time of an aircraft due to electrical problems will be less. However the daily or differential Opportunity cost of a down aircraft is the same regardless of the type cable system. The cost differential is identified where one system has fewer down days.
4.2.1.1.1 Government Organizational Maintenance Personnel	0.7	0.9	The assumed reliability of fiber optic equipments or systems causes this cost to be less than a simular cost for a coax system.
4.2.1.3 Government Support Equipment Maintenance	1.0	1.5	Support and test equipment presently in the inventory will remain even after the introduction of fiber optic cable. The additional cost will be recognized as that required to maintain the unique or peculiar support and test equipment which was developed under cost element 1.2.1.8.

Table II (continued)

OPPERATING AND SUPPORT

Cost Element	Fiber Optic Cost Minimum	Fiber Optic Cost Maximum	Remarks
4.2.2.3 Government Spare Parts and Repair Material	0.7	0.9	The assumed reliability of fiber optic equipments or systems should reduce the cost of repair parts consumed during maintnenace.
4.2.2.4.1 Government Supply Investory Management	1.1	1.3	Coax system components are already a part of the supply system. There will be a cost associated with introducing the new components of the fiber optic technology.

fiber optic cable which enhance its use as a signal carrying conductor are listed in columnar form on the left side of the table. Across the top of the table are listed the differential cost elements previously identified. If a fiber optic performance characteristic could significantly impact upon a differential cost element, an (X) was placed in the tabular matrix. It should be noted that this matrix was used by the authors for the initial first approximation to each differential cost element and is subjec t to revision as fiber optic cost data becomes more readily available.

Coax cable does not inherantly posess the performance characteristic of fiber optic cable. A similar matrix presenting the lack of these performance characteristics inherant in coax cable would be a simple mirror image of Table I.

In order to standardize the meaning of each fiber optic performance characteristic listed in Table I, the authors have included a definition of each characteristic. The following definitions were compiled from various technical documents published by the fiber optic industry and NELC.

HIGH TEMPERATURE TOLERANCE - temperatures up to approximately 150°C can be tolerated by fiber optic cable.

VIBRATION TOLERANCE - fiber optic cable can tolerate vibrations without experiencing electrical problems such as internal cable short circuits or changing electrical conducting characteristics.

NO CROSS - TALK - adjacent cables within cable bundles or cable harnesses are not susceptible to stray signals induced due to their close proximity.

RFI/EMI/NOISE IMMUNITY - external electrical signals do not adversely affect the light signal within a fiber optic cable. There is no electrical signal to be either radiated or be susceptible to stray electrical signals.

TOTAL ELECTRICAL ISOLATION - there is no electrical current path within a fiber optic cable. This characteristic allows interconnected equipments to be electrically isolated from each other as well as isolated from the interconnecting cables.

NO SPARK/FIRE HAZARD - the total back of electric current within the fiber optic cable reduces the potential for spark generation to zero. This has a direct impact upon combustible ignition caused by sparks.

NO SHORT CIRCUIT LOADING - since fiber optic cables do not carry electric current, damage to a cable could not cause an electrical signal reflection back to an equipment, which could cause an equipment failure.

EMP IMMUNITY - similar to the RFI/EMI/NOISE IMMUNITY, nuclear radiation does not have a severe impact upon fiber optic cable.

NO CONTACT DISCONTINUITY - a light signal does not require a physical contact at signal connector interference, it can pass through an air gap.

WIDE SIGNAL BANDWIDTH - fiber optic cable has a wider bandwidth than either the present "twisted pair" cable or installed coax cable, however, the LED is the limiting factor for signal bandwidth.

CORROSION RESISTANT - common but severe environmental characteristics which affect electrical signal carrying cable have little or no affect upon the fiber optic cable signal quality.

HIGH SECURITY - fiber optic cable does not have the adverse characteristic which would allow it to radiate a signal that could be coupled and picked up in a non-secure environment.

SMALL SIZE - the diameter of present and the future fiber optic cable is equal to or less than that of a equivalent use coax cable.

LIGHT WEIGHT - fiber optic cable is lighter weight than an equivalent use coax cable.

REDUCED SAFETY HAZARD - the high temperature tolerance and no spark hazard characteristics coupled together allow fiber optic cable immunity to exclusion from location in a hazardous area.

REDUCED ELECTRICAL POWER REQUIREMENTS - fiber optic light transmitting and receiving modules have the potential to require less electrical power to operate than an equivalent coax cable system.

B. COST ELEMENT COMPARISON DEVELOPMENT

Cost data is available for equipment or systems using coax cable. Similar cost data for equipment or systems using fiber optic cable is not necessarily available since fiber optics is an infant technology and only a limited cost data base has been collected. This lack of available cost data requires that many of the fiber optic costs be "best estimates." In order to facilitate a best estimate approach to determining costs, each fiber optic cost was formulated as a multiple of coax cost for the same cost element. This was done on an element-by-element basis using the substitution:

$$C^*_{fo} = A\ C_{cc} \text{ where } A = \frac{C^*_{fo}}{C_{cc}} \text{ and}$$

C^*_{fo} is the cost of the fiber optic alternative of a specific cost element

C_{cc} is the cost of the coax cable alternative of the same element,

A is the relative cost of the fiber optic alternative as a percentage of the known coax cable cost.

The source of actual cost data for coax cable equipment or systems is generally limited to aircraft manufacturers since they hold the expertise required to wire aircraft using present coax technology. With the use of known coax cost data for a specific task, a cost comparison for the same task can be determined in order to transition between two technologies. Because of the uncertainty associated with some costs, the fiber optic estimated cost is presented in the form of a cost range; a minimum value and a maximum

value. Uncertainty associated with any cost element is an indication of areas for future investigation. As the fiber optic technology advances, these first approximation costs will require refinement. It can be expected that over time, a future analysis effort will be required to revise both the minimum and maximum values of the estimated cost range. Chapter IV contains the authors' recommended procedures for future cost data collection.

Table II contains the authors' first approximation to the "best estimate" cost comparison between fiber optics and coax. As an example of the method used to develop a first approximation cost estimate, consider cost element 3.1.6.2 CONTRACTOR SITE/SHIP/VEHICLE CONVERSION during production. Table I indicates that all fiber optic performance characteristics could significantly impact (tend to reduce) this cost element. It is the authors' judgment that these superior fiber optic performance characteristics would be considered and utilized during the development and design effort; to reduce the subsequent installation (conversion) effort and cost. Accordingly, the authors' maximum estimate for "A" in the equation:

$$A = \frac{C^*_{fo}}{C_{cc}} = \frac{\text{Cost contractor site/ship/vehicle conversion (fiber optic)}}{\text{Cost contractor site/ship/vehicle conversion (coaxial cable)}}$$

was established less than or equal to 1. In a similar manner the lower bound was estimated at 0.7.

$$0.7 \leq A \leq 1$$

In sum, the <u>authors</u> estimate that the cost of operforming the task identified by cost element 3.1.6.2 could range between the limits of:

(a) the task performed using fiber optics with a minimum cost of 70 percent of the same task performed using coax.

(b) the task performed using either fiber optics or coax would have a maximum cost equal to the cost of coax.

The significant of this result is that a general cost estimation process has been developed to permit cost estimation and direct comparison of two alternative technologies in the conceptual stage of development.

In the above example, the <u>authors</u> estimated that the fiber optic alternative offered superior cost advantages for element 3.1.6.2. The basis for this estimation was a combination of knowledge gathered during interviews, research, intuition, and judgment. All estimation concerns judgment. The purpose of this approach is to structure and direct the estimation process so that multiple expert judgments can be utilized and synthesized to a "statistically" significant "best estimate." This matter will be further discussed in Chapters IV and V. Table II contains the <u>authors'</u> "best estimate" of all cost comparisons relevant to the fiber optic development decision. As cost data is gathered as recommended in Chapter IV, the estimates shown in Table II will require revision to improve their accuracy.

Actual cost data has been collected and appears in Appendix I as a preliminary estimate.

IV. METHODOLOGY TO DETERMINE COST ELEMENT VALUES

A. PURPOSE

This chapter is dedicated to identifying the costing and data gathering methodology necessary for each differential cost element. Differential cost elements were selected as the most appropriate in order to facilitate the decision process addressed in Chapter I. The differential cost elements are those cost elements previously identified in Chapter II.

B. SPECIFIC COST ELEMENT ANALYSIS

The Differential Life Cycle Cost model elements previously developed in Chapter II are the relevant LCC elements which must be determined. It was apparent that either a cost estimating relationship (CER) or alternative estimating procedure would be required for each element. An attempt was made to first identify a previously established CER. If a previously established CER was not available, alternative costing methodology was sought. Some of the cost estimating relationships were obvious and could be expressed in simple terms. For a variety of reasons, other relationships were not so obvious and many times there was no relationship in existence.

A direct method of estimating costs is with the use of a cost estimating relationship (CER). A CER is defined as

an analytic device that relates the value (in dollars or physical units) of various cost categories to the cost-generating or explanatory variables associated with the categories. (38)

The problem of estimating costs for cost elements that do not have a CER can be very complex. Since the fiber optic technology is in its infancy, only limited cost data is available. In order to avoid generating unnecessary work, a determination must be made as to whether adequate cost information is already available. The DoD Instruction 7041.3, "Economic Analysis and Program Evaluation for Resource Management," (27) suggests the following categories of data sources:

(1) established reports
(2) opinion and judgments of experts
(3) observation and tabulation of steps in a work process
(4) outside organizations
(5) information centers

After an extensive search for fiber optic data transfer system technology cost data, the authors compiled the following list of data source categories:

(1) aircraft manufacturers
(2) fiber optic manufacturers/R&D activities
(3) historical files
(4) Chief of Naval Education and Training (CNET)
(5) Department of Defense (DoD) activities.

This is a general list of data source categories and is by

no means exhaustive. As the technology advances and greater uses are found for fiber optic data transfer systems this list of data sources will expand. Table III is a matrix presentation of all differential cost elements and the possible data sources. This was developed as a "quick-look" data source guide to enable the authors to rapidly determine which cost elements could be calculated using a CER and which elements would require some other data collection technique.

An expanded version of the quick-look data source guide is presented in Appendix K. Each differential cost element is again identified and the authors' recommended procedure for data collection is presented.

All differential cost elements were divided into one of three groups; those having: (a) cost estimating relationships, (b) a limited cost data base, (c) historical costs. Those cost elements for which no previously established cost estimating relationship was developed were further classified as:

<u>Category I:</u> Cost elements for which only limited published cost data is available. It contains the largest number of cost elements which are of the type:

(a) contractor engineering during R&D

(b) contractor development tests

(c) contractor manufacturing costs.

<u>Category II:</u> Which comprised the remaining cost elements; which by their nature have either a historical data base or

DIFFERENTIAL COST ELEMENT \ DATA SOURCE	COST ESTIMATING RELATIONSHIP	AIRCRAFT MANUFACTURERS	FIBER OPTICS MANUFACTURER	HISTORICAL FILES	TRI-TAC	CNET	DOD ORGANIZATION	CATEGORY I	CATEGORY II	QUESTIONNAIRE CROSS REFERENCE
1.2.1.2		X						X		III-1
1.2.1.4		X						X		III-2
1.2.1.5		X						X		III-3
1.2.1.8		X						X		III-4
1.2.1.10		X		X					X	III-5
1.2.2.3				X			X		X	
2.1.3.4		X						X		IV-1
2.1.4		X						X		IV-2
2.1.5	X									
2.1.6.3.2		X		X				X		IV-3
2.1.10		X						X		IV-4
2.1.12		X		X					X	IV-5
2.2.2.2						X			X	
2.2.2.3.2	X				X					
2.2.2.3.3	X				X					
3.1.1		X						X		V-1
3.1.2.1			X					X		*
3.1.2.2			X					X		*
3.1.2.3			X					X		*
3.1.3		X						X		V-2
3.1.6.2		X						X		V-3
3.1.6.3		X						X		V-4
3.1.8				X					X	
4.1.6	X									
4.2.1.1.1	X									
4.2.1.3	X									
4.2.2.3	X									
4.2.2.4.1	X									

DATA SOURCES FOR DIFFERENTIAL COST ELEMENTS

TABLE III

there exists within DoD, activities which have the capability to determine the cost data in question. These cost elements are of the type:

(a) contractor G&A costs

(b) Government test and evaluation (T&E)

(c) Government training devices and equipment.

The actual data collection will not be conducted by the authors. This will be a future effort by either a contractor or the Naval Postgraduate School.

Of the data source categories previously determined, there were two selected as primary sources for the required cost data: (1) aircraft manufacturers and (2) fiber optic manufacturers/R&D activities. Aircraft manufacturers are a rather small population and can be readily identified. To reduce the formidable task of identifying the many fiber optic manufacturers/R&D activities, the Naval Electronics Laboratory Center (NELC) was asked for assistance. NELC has established a dynamic set of composite distribution lists for use in exchanging data and reports with Government facilities and industry pertaining to the rapidly evolving fiber optics technology. NELC sorted and classified the data sources as to their particular interest and activities by the use of the data collection form shown in Figure 2-IV-1. Constructing a list of actual data sources will be a part of the future data collection effort using aircraft manufacturing listings and the fiber optics composite distribution list at NELC. In order to facilitate future data collection for

DO NOT MARK – FOR INTERNAL USE ONLY

CARD NO.		ADDRESS SEQ. NO.							
71	72	73	74	75	76	77	78	79	80

INDICATE PREFERENCES FOR YOUR PARTICIPATION IN INTERCHANGE

DESIRE TO PARTICIPATE	DO NOT DESIRE TO PARTICIPATE	CHANGE OF CONTACT/ADDRESS	CHANGE OF CLASS./CATEG.
36	37	38	39

INDICATE APPROPRIATE CLASSIFICATIONS THAT DESCRIBE YOUR ORGANIZATION OR AGENCY

UNITED STATES	NON U.S.	DEPT. OF DEFENSE	OTHER GOVT. AGENCY	CORPORATE INDUSTRY	ACADEMIC INSTITUTION	NON-PROFIT RESEARCH	PROFIT ORIEN. RESEARCH
40	41	42	43	44	45	46	47

INDICATE THE PRIMARY CATEGORY OR CATEGORIES THAT BEST DESCRIBE THE FIELD OF THE FIBER OPTICS TECHNOLOGY THAT YOUR ORGANIZATION/AGENCY INTENDS TO PARTICIPATE IN AND CONTRIBUTE TO IN THIS INTERCHANGE. PLEASE LIMIT CHOICES.

BASIC RESEARCH	DEVELOPMENT	PRODUCTION/ MANUFACTURING	LED's	OTHER LIGHT SOURCES	OPTICAL COUPLERS AND CONNECTORS	ELECTRO-OPTIC CIRCUITS	HYBRID CIRCUITS	INTEGRATED OPTICAL CIRCUITS	OPTICAL BULK GLASS	OPTICAL BULK PLASTICS	OPTICAL FIBERS	CABLING OF FIBER OPTICS	LIGHT DETECTORS	GRINDING & POLISHING	TERMINATION & SPLICING METHODS	AVIONICS APPLICATIONS	SHIPBOARD APPLICATIONS	LAND BASED APPLICATIONS	OTHER(S) (SPECIFY)			
48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70

1. CONTACT NAME
2. TITLE
3. CODE OR MAIL STOP
4. ORGANIZATION OR AGENCY NAME
5. ADDRESS
6. CITY
6. STATE
6. ZIP CODE
7. COUNTRY (IF NOT U.S.)
8. AREA CODE AND PHONE NO. — AUTOVON

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

DATA COLLECTION FORM

FIGURE 2-IV-1

those cost elements not having an established CER, the authors investigated the cost estimating techniques of engineering methods, analogy and Delphi. The result of this investigation was a composit cost estimating technique. It is the authors' contention that engineering estimates by experts in industry is an appropriate cost estimating method for this analysis. Engineering estimates in a new technology can be transformed into relative estimates by using an analogy of a similar engineering task in a known technology. An effective method to gather engineering estimates based upon an analogy is with the use of a Delphi Questionnaire.

Delphi is a method of technological forecasting which uses a questionnaire to poll experts who are actually attempting to accomplish a specific task addressed by the questionnaire. As with any method of technological forecast casting, the Delphi Questionnaire has both advantages and disadvantages. For an indepth study of the Delphi Technique the authors recommend references 45 and 57.

Two Delphi Questionnaires have been designed for future data collection. One for use by the aircraft industry and the second to be used by the fiber optic industry and are displayed in Appendices H and L.

The Delphi Questionnaire for use by the aircraft industry has been divided into five sections:

I. Respondent Identification

II. Fiber Optic Performance Characteristics

III. Research and Development Costs

IV. Non-Recurring Investment Costs

V. Recurring Investment Costs.

Each aircraft industry respondent would receive Sections I and II combined with one of the remaining three sections depending on the area of expertise being surveyed.

The Delphi Questionnaire for use by the fiber optic industry found in Appendix H consists of two sections:

I. Respondent Identification

II. Fiber Optics State-of-the-Art

The objective of the Delphi Questionnaire is to gather cost data from qualified personnel. To determine cost estimates for the required DIFFERENTIAL cost elements, two properly designed Delphi Questionnaires will conform to one or more of the following applicable requirements:

(1) be submitted to qualified technical/managerial representatives working in the field of fiber optics to determine future predicted costs, production rates, state-of-the-art breakthroughs,

(2) be submitted to qualified technical/managerial representatives working in the aircraft industry in order to determine relative engineering cost estimates of a representative coax cable task performed using fiber optics.

(3) be submitted to qualified personnel familiar with establishing training requirements and establishing schooling and training courses.

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LIFE CYCLE COSTING OF AN EMERGING TECHNOLOGY: THE FIBER OPTICS --ETC(U)

MAR 76 C R JONES, R L JOHNSON, E W KNOBLOCH

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A031 839

(4) be divided into sections which can be addressed by personnel of either (a) the fiber optic industry, (b) the aircraft industry, or (c) the field of military education and training.

(5) identify the qualifications of the person completing the questionnaire.

The Delphi Questionnaire for use within the aircraft industry, found in Appendix L, is designed to determine the major cost categories, Research and Development, Non-Recurring Investment and Recurring Investment. In an effort to minimize ambiguity and personal bias of the respondents, each section of the questionnaire establishes a baseline scenario. Each question within a section is then based upon the scenario for that specific section of the questionnaire and the list of Fiber Optic Performance Characteristics found in Section II of the questionnaire. The respondents are requested to estimate the relative cost of performing a specific task using fiber optic technology as a substitute technology for coax. The estimated relative cost of using fiber optics is expressed as a multiple of the cost of using coax.

The Delphi Questionnaire for use by the fiber optic industry relies mostly upon state-of-the-art advances and judgment. It is straightforward and requires no detailed explanation.

To determine which cost elements require the use of a Delphi Questionnaire as the data collection method, reference can be made to Table III. Each cost element has been

identified as being of the Category I or II type or having an established CER. Correlation between a specific cost element and a Delphi Questionnaire question is with the column labeled QUESTIONNAIRE CROSS REFERENCE. The numbers in the QUESTIONNAIRE CROSS REFERENCE column refer to the aircraft industry Delphi question numbers.

Only three cost elements require an input from the fiber optic industry and the application of the Delphi Questionnaire is explained in Appendix K under cost elements:

3.1.2.1 Contractor purchased parts and equipment for production

3.1.2.2 Contractor subcontracted production items

3.1.2.3 Contractor production material.

Table III column headed QUESTIONNAIRE CROSS REFERENCE is marked with an Asterisk (*) to indicate the use of the fiber optic industry Delphi Questionnaire found in Appendix H.

The process of data collection through the use of a Delphi Questionnaire is iterative. Cost data collected from an initial survey is expected to be distributed within a cost range for each cost element surveyed. The numerical spread of this initial cost estimate is dependent upon the:

(a) qualifications of the questionnaire respondent,

(b) number of respondents,

(c) availability of data,

(d) ambiguity inherent within the questionnaire,

(e) respondents' individual bias and interpretation of each applicable question.

An iterative process will be required to modify the questionnaire(s) as problem areas, such as widely distributed cost estimates for a specific element, are discovered. As survey cost data is collected, it can be anticipated that specific cost areas will require further investigation.

Due to the time limitations of this study, the two Delphi Questionnaires presented in this chapter have not been validated and are presented as an initial point of departure for subsequent questionnaire design efforts. A thorough questionnaire review is recommended prior to using these two questionnaires for industry surveys.

A follow-on effort conducted by the NPS did use the Delphi Questionnaires found in Appendices H and L to gather data from both the fiber optics and aircraft industries. Cost data for all applicable cost elements was collected during the follow-on effort with the results presented in Appendix I.

V. SUMMARY, CONSIDERATIONS, FINDINGS AND RECOMMENDATIONS

A. SUMMARY

The purpose of this study was to develop an appropriate life cycle cost model for the A-7 ALOFT economic analysis to assist in determining whether further development of an airborne fiber optic data transfer system is warrented and can be justified. Because of the nature of the development decision, and the current conceptual phase of the A-7 ALOFT project, a comparative or differential cost model consisting of twenty-eight cost elements was defined (see Figure 2-II-11). The differential model was developed by a systematic element-by-element analysis, displayed within Appendix J, which preceded from the general TRI-TAC cost model of Figure 2-II-8 This analysis additionally identified a total fiber optic life cycle cost model as defined in Figure 2-II-10 for future budgetary purposed. In view of the planned iterative nature of the A-7 economic analysis, assumptions and considerations were specified in some detail throughout the analysis to ensure a systematic approach and traceability of results.

Estimating relationships for the differential cost model elements were next sought. While the nature and results of this search will be discussed in the next section, the unavailability of data and infant state of the fiber optic technology suggested that industrial surveys of some type would be required. To design such surveys and provide a

direct cost comparison of the two alternatives, the fiber optic life cycle cost model was structured in Chapter III to express fiber optic life cycle costs as a multiple of the identical coaxial cable life cycle cost elements. A first estimation of the relative cost coefficients was prepared by the authors, based on fiber optic characteristics and the probable impact of such characteristics on the associated cost element in Table II. The above scheme is quite simple, and general, yet provides the analysis, and the analyst, a means to directly compare identical functions in two different technologies. Uncertainty in assigning the multiple, alerts the analyst to those elements where uncertainty exists or additional information is needed. Last but not least, structuring the problem in this manner permits cost comparisons of a new technology based on costs developed in a known technology.

Twenty-eight differential cost elements for coaxial cable specified in Figure 2-II-11 are redefined in Table IV where:

a. R_{it} = cost of the R&D elements,
$i=1 \ldots 6,\ t=1 \ldots 10$

b. I_{jt} = non-recurring investment costs,
$j=1 \ldots 9,\ t=1 \ldots 10$

c. D_{kt} = recurring investment costs,
$k=1 \ldots 8,\ t=1 \ldots 10$

and d. O_{lt} = operational/support costs,
$l=1 \ldots 5,\ t=1 \ldots 10$

then the coaxial cable life cycle costs are:

LCC ELEMENT SUBSTITUTION

Let: R_{1t} = Coaxial cable cost of LCC element 1.2.1.1 in year t.

R_{2t} = Coaxial cable cost of LCC element 1.2.1.4 in year t.

R_{3t} = Coaxial cable cost of LCC element 1.2.1.5 in year t.

R_{4t} = Coaxial cable cost of LCC element 1.2.1.8 in year t.

R_{5t} = Coaxial cable cost of LCC element 1.2.1.10 in year t.

R_{6t} = Coaxial cable cost of LCC element 1.2.2.3 in year t.

Let: I_{1t} = Coaxial cable cost of LCC element 2.1.3.4 in year t.

I_{2t} = Coaxial cable cost of LCC element 2.1.4 in year t.

I_{3t} = Coaxial cable cost of LCC element 2.1.5 in year t.

I_{4t} = Coaxial cable cost of LCC element 2.1.12 in year t.

I_{5t} = Coaxial cable cost of LCC element 2.1.6.3.2 in year t.

I_{6t} = Coaxial cable cost of LCC element 2.1.10 in year t.

I_{7t} = Coaxial cable cost of LCC element 2.2.2.2 in year t.

I_{8t} = Coaxial cable cost of LCC element 2.2.2.3.2 in year t.

I_{9t} = Coaxial cable cost of LCC element 2.2.2.3.3 in year t.

Let: D_{1t} = Coaxial cable cost of LCC element 3.1.1 in year t.

D_{2t} = Coaxial cable cost of LCC element 3.1.2.1 in year t.

D_{3t} = Coaxial cable cost of LCC element 3.1.2.2 in year t.

D_{4t} = Coaxial cable cost of LCC element 3.1.2.3 in year t.

D_{5t} = Coaxial cable cost of LCC element 3.1.3 in year t.

D_{6t} = Coaxial cable cost of LCC element 3.1.6.2 in year t.

D_{7t} = Coaxial cable cost of LCC element 3.1.6.3 in year t.

D_{8t} = Coaxial cable cost of LCC element 3.1.8 in year t.

Table IV

Table IV (continued)

Let: O_{1t} = Coaxial cable cost of LCC element 4.1.6 in year t.

O_{2t} = Coaxial cable cost of LCC element 4.2.1.1.1 in year t.

O_{3t} = Coaxial cable cost of LCC element 4.2.1.3 in year t.

O_{4t} = Coaxial cable cost of LCC element 4.2.2.3 in year t.

O_{5t} = Coaxial cable cost of LCC element 4.2.2.4.1 in year t.

$$C = \sum_{t=1}^{10} n_t \left(\sum_{i=1}^{6} R_{it} + \sum_{j=1}^{9} I_{jt} + \sum_{k=1}^{8} D_{kt} + \sum_{l=1}^{5} O_{lt} \right)$$

where n_t = the discount factor for year t, t = 1 ... 10.

If the substitution, $R^*_{it} = A_{it}\ R_{it}$ $\quad$ i=1 ... 6, t=1 ... 10

represents the Research and Development cost elements for fiber optics expressed as a multiple of the identical coaxial cable cost element

where $$A_{it} = \frac{R^*_{it}}{R_{it}}$$

and similar substitutions are made for the recurring, non-recurring and operational support categories, then the differential fiber optic life cycle cost can be specified as:

$$C^* = \sum_{t=1}^{10} n_t \left(\sum_{i=1}^{6} A_{it}\ R_{it} + \sum_{j=1}^{9} A_{jt}\ I_{jt} + \sum_{k=1}^{8} A_{kt}\ D_{kt} + \right.$$

$$\left. + \sum_{l=1}^{5} A_{lt}\ O_{lt} \right)$$

where n_t is the discount factor for year t. Differential costs as utilized herein are costs which differ between the alternatives as defined in Chapter I; and should not be confused with incremental costs or the difference between the life cycle costs of the alternatives used by some authors.

The R_{it}, I_{jt}, D_{kt}, and O_{lt} represent differential cost element coaxial cable life cycle costs which will be calculated by McDonnell Aircraft Company for the A-7 ALOFT Economic

Analysis. Calculation of differential fiber optic life cycle costs will, therefore, depend on developing reliable estimates of the appropriate A_{it}, A_{jt}, and A_{kt} relative cost coefficients. The A_{lt} relative cost coefficients need not be estimated since explicit cost estimating relationships (CER) are available for the O_{lt} costs. Chapter IV contains the development of explicit CER's for these operating and support cost categories and for their non-recurring investment costs, I_{3t}, I_{8t}, and I_{9t}. With these exceptions, and for reasons specified under Considerations, the remaining cost categories and the relative cost coefficients will require an industrial survey. Delphi Surveys, structured to identify the required A_{it}, A_{jt}, and A_{kt} relative cost coefficients, are developed in Appendices H and L for use in a follow-on study. (see Appendix I)

B. CONSIDERATIONS

1. Data Availability

Information and cost data needed to develop aircraft data transfer system and fiber optic cable and component costs is currently unavailable. Reference 69 outlined the fiber optic costing problem and recommended an industrial experience curve approach for projecting possible fiber optic material costs. This study placed major emphasis on the development of an A-7 ALOFT LCC model, the identification of relevant costs, and how to estimate them. Despite an extensive literature search and library review, little

published information was found. Discussions with knowledgeable government and non-government personnel in the electrical interconnect field revealed that cost is not a primary consideration on developing electrical systems, and that aircraft manufacturers are the primary source of any information which exists.

There are two major reasons for this situation. First, the aircraft manufacturers have a virtual monopoly on aircraft electrical engineering knowledge and technology because they are the sole practitioners. This has resulted, possibly for proprietary reasons, in little published data concerning the field in general (only two text books were located (94) and (97) both English and both dated) and aircraft systems in particular. Second, aircraft manufacturers have historically not aggregated costs at the electrical interconnect subsystem level.

Aircraft electrical system costs have primarily been aggregated within airframe costs, and airframe costs have historically been aggregated in functional categories such as Engineering, Manufacturing, Tooling, etc.(61) The lack of published electrical interconnect system cost-data, precludes either an analysis of interconnect system cost relationships, or the development of cost estimating relationships for fiber optic systems based on them. This lack of historical data also requires a reliance on analagous cost estimating methods to develop comparative fiber optic costs. The extremely limited published information on the

subject of aircraft electrical engineering practice supports this thesis. "The electrical design engineer often finds himself with requirements to electrically interconnect numerous avionic systems and associated equipment panels and boxes often structural design is firm, armament designated, hydraulic routing completed and cooling and heating installed."(90) "It must be emphasized that system selection is not, or is ever likely to be, a precise science. It cannot be determined by mathematical methods alone, since final selection is controlled by many aspects both technical and practical. Intuition and experience are the most valuable tools of the designer (electrical systems), and are never more useful than in assessing the best system arrange- for a particular aircraft."(94)

In summary, there is very little published information on how electrical systems are developed, their historical costs, how such costs are established or the retrievability of such costs. This information apparently exists only within the corporate memories of airframe manufacturing firms. For example, a value engineering estimate for an A-7E type electrical interconnect system, (Figure 2-V-1) provided the authors. Although the basis and accuracy of this estimate is unknown, the relative size of the various cost categories is of interst and the ability of LTV to develop such estimates demonstrates the feasibility of an industrial survey approach.

A-7E Type Electrical System

(Value Engineering Estimate Only)

Non-Recurring Costs Engineering Development, etc.	3.2 M
Non-Recurring Costs Tooling and Manufacturing, etc.	3.0 M
Recurring Costs Material	50.0 K
Labor and other	109.0 K
Total	6.359 M

Source: LTV Aircraft Company Personnel

Figure 2-V-1

2. Model Development

For the above reasons, the emphasis of this study has been to structure a cost model to support an industrial survey approach using analogous type cost estimating techniques.

Military Equipment Cost Analysis by the Rand Corporation indicates: "Because a private concern generally has information only on its own products, much of the estimating in industry is based on anology, particularaily when a firm is venturing into a new area."(86) Figure 2-V-2 displays the A-7 ALOFT differential cost model as developed in this study, including relative cost coefficients estimated by the authors in Chapter III. The relative cost coefficients were estimated by the authors on the basis of fiber optic characteristics, program assumptions, the state of the A-7 ALOFT development, etc., and the anticipated affect of such factors on the particular cost element. Note that a range of values were established for each relative cost coefficient displayed and that the relative cost coefficient is considered in this display as a constant in respect to time.

That is: $A_i = A_{it}$, $A_j = A_{jt}$, $A_k = A_{kt}$

for all t, t = 1 ... 10.

The formulation of the model in this manner is to facilitate the relative comparison of costs at the level of aggregation desired in order to simplify industrial survey techniques needed to develop comparitive costs during the

FIBER OPTIC LIFE CYCLE COST =
TEN-YEAR DISCOUNTED SUM OF THE FOLLOWING COST ELEMENTS:

*NOTE: parenthesis before the R_{it}, I_{jt}, and D_{kt} repre represent the range of the A_{it}, A_{jt}, and A_{kt} estimated in Table II.

+ (1.0 - ?) R_{1t}
+ (1.0 - ?) R_{2t}
+ (1.0 - ?) R_{3t}
+ (1.0 - 2.0) R_{4t} (Research & Development Costs)
+ (1.0 - 1.8) R_{5t}
+ (1.0 - 1.8) R_{6t}

+

+ (1.2 - 1.8) I_{1t}
+ (0.6 - 1.0) I_{2t}
+ I_{3t}
+ (0.9 - 1.0) I_{4t}
+ (1.2 - 2.0) I_{5t} (Non-Recurring Investment Costs)
+ (1.2 - 1.8) I_{6t}
+ (2.0 - 3.5) I_{7t}
+ I_{8t}
+ I_{9t}

+

Figure 2-V-2

Figure 2-V-2 (continued)

$+ (.8 - 2.0) D_{1t}$

$+ (.8 - 2.0) D_{2t}$

$+ (.8 - 2.0) D_{3t}$

$+ (.8 - 2.0) D_{4t}$ (Recurring Investment Costs)

$+ (0.7 - 0.9) D_{5t}$

$+ (0.7 - 1.0) D_{6t}$

$+ (0.85 - 1.0) D_{7t}$

$+ (0.9 - 1.0) D_{8t}$

$+$

$O_1 + O_2 + O_3 + O_4 + O_5$ (Operational/Support Costs)

program's conceptual phase. For example, it seems more practical and reasonable to ask an expert in tooling to compare and assess differences in total tooling costs of the fiber optic/coaxial cable alternatives, rather than the annual estimates of such costs. While it is conceptually more appealing to treat the relative value coefficients as a variable with time, because of the time phasing of the costs, the resultant benefits of such a procedure must be weighed against the more complicated estimation process which will result. In addition, the relative value coefficients may indeed be constants, or essentially so, for the period under consideration; and industrial estimating practice may suggest that annual estimates are feasible and desired. In either case, the cost model should be structured to facilitate the survey techniques by utilizing methods of aggregation, which best suit the industrial estimation process and the model's purpose.

The purpose of this model is to compare relevant fiber optic/coaxial cable life cycle costs. Because the knowledge, information, and historical data needed to develop such cost estimates resides in the aircraft and fiber optic industries, the model was structured to support analogous estimates utilizing industrial surveys. The nature of this problem is identical to many state-of-the-art costing problems during the conceptual stage of development. That is parametric methods are not available, engineering design approaches are time consuming, costly, and potentially biased; and industrial

analogous estimating approaches are too often unreliable due to the limited data bases upon which they are developed.

The A-7 ALOFT LCC model was structured to take advantage of: industrial familiarity with analogous estimating techniques, expert opinion, estimation, and comparison at well defined levels of aggregation; and survey methods to develop statistically significant sample sizes. The use of relative cost coefficients allow the problem to be disaggregated into various levels of expertise and direct functional/material comparisons so that a final estimate can be synthesized from a number of independantly provided industrial/government estimates. Delphi surveys to develop the required A_i, A_j, and A_k relative cost coefficients for the A-7 ALOFT model are developed in Appendices H and L. An initial survey of all aircraft manufacturers and firms interested in the aircraft data transfer application was envisioned, with subsequent surveys based on initial results and statistical analysis. This iterative survey approach would provide the means to limit and identify areas of costing uncertainty, and provide a more reliable fiber optic data transfer system cost estimate based on a multiple firm industrial sample.

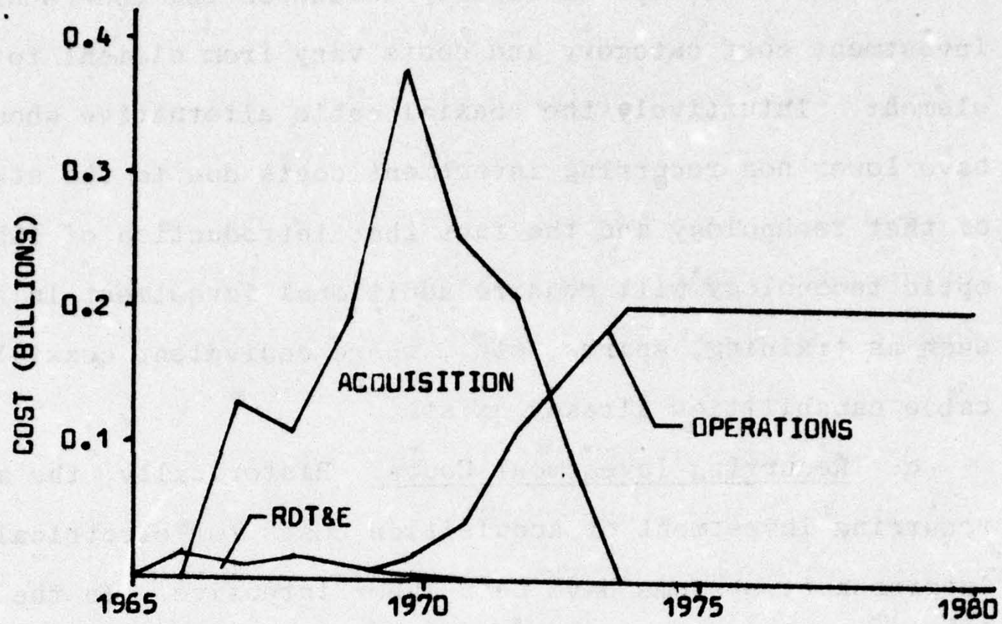
3. <u>An A Priori Cost Estimate</u>

While the actual cost quantification of the A-7 ALOFT fiber optic date transfer system has been developed by a follow-on effort (see Appendix I), it is pertinent to consider what can be summarized at this stage of the economic analysis.

If one views the fiber optic life cycle cost model (see Figure 2-V-2) in board perspective and considers the relative cost coefficients, a direct comparison between fiber optic and coaxial cable cost elements is displayed within the four cost categories. In addition, Figure 2-V-3 displays the ten year life cycle cost curves for the A-7D to illustrate the distribution and timing of a major systems cost.

a. Research and Development Costs: Historically, development costs have represented a small percentage of total life cycle costs at least for major systems like the A-7D. Because of the state of fiber optic development, and the state of fiber optic experience within the airframe industry, a greater development cost for fiber optics can be anticipated for the A-7 ALOFT application. However, because of less restrictive design characteristics and reductions in testing which can be anticipated as fiber optic experience grows, future development costs for this application or development costs of a full vice subsystem application would be expected to be greatly reduced. In any respect, the authors' uncertainty in projecting relative cost coefficients for these cost elements points to the need for greater investigation in this area and expert opinion.

b. Non-Recurring Investment Costs: Historically, investment or acquisition costs have been the decisive factor in making system decisions. Acquisition costs for major systems have represented approximately 45 to 47 percent of the LCC



A-7D LIFE CYCLE COSTS

SOURCES:	RDT&E	- Senate Hearings	1966-1973
	ACQUISITION	- Senate Hearings	1966-1973
	OPERATIONS	- AFM 173-10	1973

Cumulative LCC After 10 Years of Operations

	Billions	Percent
RDT&E	$0.584	2.0
ACQUISITION	1.332	45.6
OPERATIONS	1.528	52.4
	$3.444	100.0

Figure 2-V-3

after 10 years of operations. As can be seen from Figure 2-V-2, neither candidate system clearly dominates the non-recurring investment cost category and costs vary from element to element. Intuitively the coaxial cable alternative should have lower non-recurring investment costs due to the state of that technology and the fact that introduction of fiber optic technology will require additional investment in areas such as training, spares, etc., where equivalent coaxial cable capabilities already exists.

c. Recurring Investment Costs: Historically, the major recurring investment or acquisition costs for electrical interconnect systems have been labor intensive. In the A-7E value estimate the ratio of labor/overhead costs: direct material costs were 105K:50K. The ratio for an F-4N is estimated to be 65K:35K. The alternative fiber optic or coaxial cable systems will significantly reduce future labor related production costs because of the order of magnitude reductions in the number of cables to be installed. Tables V and VI display the comparitive costs of the present A-7 ALOFT wire interconnect system and its fiber optic replacement, which are about equal if multiplexing/demultiplexing costs are ignored. In sum, fiber optic/coaxial cable systems will cost more than present wire systems, at least initially, and these costs will be more material than labor related.

Emphasis has been placed on developing projections of future fiber optic costs. Although the need to develop such estimates is not underestimated, the significance of

A-7 ALOFT FIBER OPTIC CABLES AND CONNECTORS

COMPONENT	TYPE	R'QRD QNTY	$COST/UNIT	TOTAL COST	UNIT WT	TOTAL
Fiber Optic Cable	Valtec (IBM P/N L20-262-1)	224 ft	$2.50/ft	560.00	1.3 lbs/100 ft	2.91
	*Valtec (P/N L20-262-2)	224 ft	2.00/ft	448.00	.68 lbs/100 ft	1.52
Single Channel Bulkhead Connectors	IBM (P/N L20-242)	13 ea	2.50 ea	32.50	.0297 lbs ea	0.38
Single Channel Pressure Bulkhead Connectors	NELC (P/N 6507)	5 ea	3.50 ea	17.50	.0499 lbs ea	0.25
Multi-Channel Bulkhead (rack-panel) Connector	ITT Cannon (P/N DBK-4B)	1 ea	***294.05	294.05	.559 lbs ea	0.55
Cost of Terminating, Polishing & Testing Final Harness	Labor	12 hrs	20.00 hr	240.00		
Cost/Weight Totals				$1,592.05		5.61

NOTES: * The first listed fiber optic cable was the cable selected by IBM for their delivery of the ALOFT system. The second listed cable is the alternative set of cables being procured by NELC in time for the Flight Test. The new cable has the same optical properties, but utilizes a new lightweight, non-conductive hytrel (c) jacket in lieu of the PVC jacketed, steel Monocoil (c) for protective packaging.

** Total reflect weight and cost of newer Valtec cable.

*** $500.00 set-up.

Table V

A-7 ALOFT DISPLACED WIRES AND CONNECTORS*

COMPONENT	TYPE	R'QRD QNTY	$COST/UNIT	TOTAL COST	UNIT WT	TOTAL WT
Coaxial Cable	RG-179B/V	222 ft	$ .1045/ft	23.20	.0170 lbs/ft	3.77 lbs
Wire, Unshielded	M22754/16-22	222 ft	.0228/ft	5.06	.00368 lbs/ft	0.82 lbs
Wire, Shielded	M17500A22/TE1T14	456 ft	.0882/ft	40.22	.0088 lbs/ft	4.01 lbs
2 Wires, Shielded	M27500A22/TE2T14	192 ft	.1405/ft	26.98	.0169 lbs/ft	3.24 lbs
3 Wires, Shielded	M27500A22/TE3T14	24ft	.1700/ft	4.08	.0206 lbs/ft	.49 lbs
Wire, 2 Shields	M27500A22/TE1V14	543 ft	.1285/ft	69.74	.0188 lbs/ft	10.21 lbs
2 Wires, 2 Shields	M27500A22/TE2V14	231 ft	.2314/ft	53.44	.0319 lbs/ft	7.37 lbs
Connector, Receptacle (212 Contacts)	CVC6092 - IN	2 ea*	30.79 ea	61.58	.72 lbs ea	1.44 lbs
Connector, Receptacle (212 Contacts)	CVC6093 - IN	2 ea*	32.81 ea	65.62	.64 lbs ea	1.28 lbs
Cost of Terminating Above and Testing Final Harness	Labor	42 hrs	20.00/hr	840.00		2.00 lbs**
Cost/Weight Totals				$1,189.92		34.63 lbs

NOTES: * These connectors are not actually replaced by the ALOFT components, but an approximately equal no. of contacts (424) are idle in the subsystems involved after ALOFT modification. In actuality these 424 signal contacts are normally distributed over 9 of these types of connectors along with power wires in the original computer interface configuration.

** This additional approximate weight is generated by the termination, potting and harnessing materials.

Table VI

material costs on both production costs and life cycle costs should also be understood. For example, cost comparisons of coaxial cable/fiber optic systems for the A-7 Aloft analysis prepared in NELC TD435 suggest that coaxial cable systems that perform equal functions are cheaper, lighter, and require less power. This may be. However, it should be recognized that these systems also represent different capabilities in terms of weight, volume, maintainability, reliability and supportability, all of which affect LCC and cost-benefit tradeoffs. A most important consideration is that present fiber optic material costs probably represent an upper bound which can be expected to decrease with time. However, on a relative comparison basis, the coaxial cable alternative will probably be cost advantageous from a production standpoint for some time into the future.

d. Operational and Support Costs: Historically, operational and support costs represent a major percentage of total life cycle costs. Operational and support costs are highly dependent on the reliability and maintainability of a system:

Maintainability: From an interconnect viewpoint, both alternatives will enhance maintainability since fewer cables are involved when compared with today's typical wire system. This reduced "look factor" is of major importance in corrective maintenance actions and the fiber optic alternative which has essentially a go/no go built in test capability should provide significant fault isolation

advantages over coaxial cable. Since the multiplexing equipment added, will affect both alternatives in a like manner, the maintainability of the system will largely depend on the fault isolation capability and the interconnect system reliability.

Reliability: Reliability measures the system's ability to perform without failure. Since all the advantages of a fiber optic data transfer system are shortcomings of coaxial cable systems, enhanced reliability is probable, despite the addition of additional components to the system such as LEDs and photo diodes. Coaxial cable system problems such as shorts, connector pin problems, cold flow, and parallel path resistance changes are eliminated in the fiber optic alternative.

Although reliability studies and tests are needed to evaluate fiber optic data system reliability, and unforeseen problems are certain to occur, the fiber optic alternative would appear simpler, more maintainable and reliable a system; and thus offer operational and support cost advantages.

In summary, the above rather intuitive but structured a priori cost analysis would suggest that the coaxial cable alternative will be developed and produced at lesser cost than an identical function fiber optic system during the FY 77-80 timeperiod, but that subsequent fiber optic operations and support costs will be less. This consideration emphasizes the need to closely evaluate the reliability

and maintainability of the fiber optic system during the A-7 ALOFT demonstration. It also suggests that analysis results may be biased by the limited size of the systems under consideration, because of the following considerations.

4. System Size Assumptions

The limited data transfer system assumed for this analysis may unrealistically bias results against the fiber optic alternative for several reasons. First, maintenance people will need to be trained in fiber optics; and fiber optic related support established at numerous locations regardless of the size of the system developed. However, the size of the system installed has important operational implications on the survivability, maintainability and weight/volume, payload/range benefits. The size of the system installed also has important design implications in that x pounds of equipment weight can translate into 4x to 7x pounds of aircraft weight.(97) It is also interesting to consider the implication on the demand for fiber optic cable and components.

The authors have asked: How much of an aircraft's installed electrical system could be replaced by fiber optics? The answers have varied between 50 - 90 percent, which appear reasonable when the distribution of designed current carrying capacity is considered. An F-4 aircraft has approximately 12 miles of installed wire, a Vickers Viscount approximately 17 miles,(94) and the Supersonic Concorde 150 miles.(72)

If 50 percent of an F-4's wiring is replaced (35,000 ft.) and 7 foot cable size assumed, 500 cables will be replaced. If the same A-7 ALOFT ratio of wire length to: fiber optic length is assumed, (1890:224) 4,147 feet of fiber optic cable will be required. For a fleet of 4200 F-4 aircraft, this would represent a fiber optic production requirement of approximately 17.5 million feet. Although this simple demand analysis was presented to emphasize the implications of a subsystem assumption, an extended analysis based on additional data could do much to scope potential aircraft demand. Such an analysis, combined with the experience curve techniques of reference 69, could provide a reasonable range of fiber optic aircraft system costs.

5. Risk and Uncertainty

Last, but not a least consideration is the question of risk and uncertainty. Table VII illustrates the cost estimating problem and the uncertainty found in early cost estimates as developed by the Electronics X Study. To offset costing uncertainty, the model developed by the authors was structured to develop a simple comparative estimating technique to direct consideration to the essential cost elements, maximize the reliability of expert and analogous estimates; and by industrial survey techniques, develop statistically significant results. Program risk is a second major area that has potentially significant cost growth programs. Table VIII also selected from the Electronics X Study,(43 and 44) is a series of questions

QUESTIONS TO BE ANSWERED
ABOUT FIBER OPTIC SYSTEMS AND SUBSYSTEMS
DURING MANAGMENT REVIEW

	Optical Data Bus (High Risk)	A-7 ALOFT (Low Risk)
* What components exists?	Most	All
* What components need new development?	Optical Couplers	None
* What is the development/test status of existing components?	Laboratory	Developed, Produced & Tested
* Are new technologies involved?	Yes	No
If so, which and what is their status?	Experimental	
* Have the components previously been integrated into a subsystem?	Yes	Yes
* If so, has it been operated outside the laboratory?	No	Yes
* Has there been subsystem OT&E?	No	A-7 ALOFT Demonstration
* How do results compare with requirements?	-	"
* What are the specific interface problems with other subsystems?	Multiple	Interface Module Milspec. Qualification
* What are the cost, performance, and schedule implications of of resolving those problems in this new development?	R&D Implications Only	Minor if full scale development is undertaken
* What are the opions if there is excess cost growth?		
a) Alternative components/ subsystems?	Yes	Coax/Wire
b) Let cost grow?	Yes	Yes
c) Reduce performance requirement?	-	No
d) Reduce force?	-	-
e) Find another way to do the job?	Yes	Yes

Table VIII

designed to develop in an uncomplicated straight-forward manner the degree of risk involved in a proposed development. Although the questions were designed to synthesize and reflect requirement and uncertainty problems of major electronics subsystems, their application to this analysis is evident. If successful accomplishment of the A-7 ALOFT demonstration is assumed, the point-to-point data transfer system represented by the ALOFT Project can be considered Low-Risk while a fiber optic Data Bus System would be High-Risk. The above techniques, and the development and use of structured scenarios outlined in reference 69, are the major methods recommended to assess and evaluate risk in the A-7 ALOFT economic analysis.

C. FINDINGS AND RECOMMENDATIONS

1. Findings

a. Life Cycle Costs

The development of reliable life cycle cost estimates by which to compare alternative systems in the early stages of a program, is a major cost estimating problem of today. Unfortunately, despite analytical interest and effort, few new tools, techniques, or concepts have evolved.

b. Data Availability

The aircraft and fiber optic industries represent the primary source of information and expertise needed to develop reliable life cycle costs for the A-7 economic analysis; due to the unavailability of parametric techniques or industrial cost data and information.

c. Cost Estimating Uncertainty

Due to the unavailability of historical cost data, the conceptual phase of the A-7 ALOFT project, and the required reliance on industrial analogous estimating techniques; the costing uncertainty is potentially high. (Reference Table VII.)

e. Model Assumptions and Results

The assumption of only a N/WDS application as defined for the A-7 Aloft LCC effort may unfavorably bias the cost benefit analysis against the fiber optic alternative by: limiting design, operational, support, and economies of scale advantages; while requiring essentially full training and support costs for a subsystem operation. See discussion in CONSIDERATIONS.

f. Projected Fiber Optic Material Costs

Time did not permit this study an extensive analysis of potential demand for fiber optic components and cable by the aircraft industry. The possibility of applying simple analogous estimating techniques to scope such a demand is discussed under CONSIDERATIONS. Such an effort combined with the experience curve techniques suggested in reference 69 could provide reasonable projections of the range of fiber optic costs.

g. A-7 ALOFT Life Cycle Cost Model

The A-7 ALOFT differential LCC model developed within this study was designed to utilize available data and estimating techniques, to identify and minimize costing

uncertainty, while providing side-by-side cost comparisons of the alternatives at levels of aggregation selected/ designed to facilitate industrial estimation.

h. Opportunity Costs

Most life cycle cost models do not explicitly address opportunity costs. In view of the conceptual development decision to be made, and the equal function but unequal reliability alternative specified; an opportunity cost element is required. (Reference Appendix K cost element 4.1.6.)

2. <u>Recommendations</u>

Findings a, b, c and d above suggested that new methods and means should be sought to develop an appropriate LCC model. The step-by-step analytical process developed to identify, classify and quantify the A-7 ALOFT model is completely general and can be applied to any program. In addition, the relative value scheme developed, in conjunction with Delphi Survey Techniques, can provide statistically significant industrial samples upon which to base cost estimates and identify major problem areas and uncertainties. In view of these findings, and the continuing nature of the A-7 ALOFT economic analysis, the following is recommended:

a. Develop and maintain a government best estimate of the relative fiber optic/coax cable costs to support continuing economic analysis efforts and decisionmaking.

b. Develop reliability/maintainability estimates for each alternative system at the earliest practical time, in order to better assess the nature of operational and support costs for each.

c. Prior to the cost benefit analysis, specify a development, production, and operations profile for the A-7 ALOFT program based on current fleet operations and practice, with which to scope and develop total force life cycle cost estimates for the A-7 ALOFT configuration.

This study has addressed a cost model structured to meet the peculiar circumstances and nature of the A-7 ALOFT cost problem. However, the process by which it was developed can provide a straight forward simple means to address future cost problems of a similarly complex nature. For this reason, both the cost and accuracy of this approach should be evaluated throughout the economic analysis to determine its cost effectiveness.

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APPENDIX A

Historical Background

I. BACKGROUND OF GLASS FIBERS/FIBER OPTICS

1. Background of Glass Fibers/Fiber Optics

Glass has been used in a multitude of applications from very early times. The earliest glass objects come from Egypt and are dated from circa 2500 B.C. The first vessels of glass were manufactured in Egypt under the 18th dynasty, particularly from the reign of Amenhotep II (1448-20 B.C.) onward. The possibility of drawing hot glass into threads was recognized in the Rhineland during the late Roman empire as well as in ancient Egypt and such threads were wound around vessels as a decoration.

In the 18th century, fine threads were prepared from a heat softened glass rod by using a "spinning wheel" process. The next development was a mechanized drawing process by attaching the fiber from the heat-softened rod to the surface of a large revolving drum. In 1908, G. von Pazsiczky replaced the rods with a refractory glass-melting chamber that had a series of holes in the bottom to provide drawing points. A different method of production was developed in 1929 whereby the application of centrifical force forced the glass through radial serrations resulting in a tangled mass of fibers. (34)

It is entirely possible that early Egyptian and Grecian Glassblowers observed the phenomenon of multiple total internal reflections in conducting light along transparent glass cylinders, and in fact, there are a number of unsubstantiated historical claims. However, the earliest recorded scientific demonstration of the phenomenon of total internal reflection was recorded by John Tyndall at the Royal Society in England in 1870. In his demonstration, he used an illuminated vessel of water to show that when a stream of water was allowed to flow through a hole in the side of the vessel, light was conducted along the curved path of the stream. D. Hondros and P. Debye followed the work of Tyndall by doing some theoretical studies on optical wave propagation in fibers in 1910, but little else was done in the way of experimentation.

The phenomenon described by Tyndall was disregarded and lay dormant until 1927, when J.L. Baird in England and C.W. Hansell in the United States considered the possibility of using uncoated fibers in the field of television to transmit and scan an image. They were followed closely by H. Lamm of Germany who used a crude assembly of quartz fibers to demonstrate the basic image and light transmission properties of fibers. Activity in this area then all but ceased for two decades. (56)

Quite unrelated to previous experiments with glass fibers as light conductors, manufacturing methods for producing glass fibers were being perfected. For example, in 1938 the Owens-Illinois Glass Company joined with the Corning Glass Works to form a new independent glass fiber firm. The company, the Owens-Corning Fiberglass Corporation, developed large-scale production methods to produce glass fibers. The spun glass method allowed continuous threads to be drawn from bushings provided with 100-400 small orifices. The threads falling from these orifices were gathered together and passed over a sizing pad onto a spool on a high-speed winder. The resulting fiber had a diameter of around 0.00022 in. (the material contained in one glass marble 3/4 in. in diameter would yield about 97 miles of single filament). (33)

A new burst of activity began in the year 1951, when A.C.S. van Heel in Holland and H.H. Hopkins and N.S. Kapany at the Imperial College in London independently initiated studies on the transmission of images along an aligned bundle of flexible glass fibers. Kapany, B.I. Hirschowitz, and others then developed optical insulation techniques which solved most of the previous light-loss problems. The resultant glass-coated glass fibers were for many years a standard optical element for use in fiber optics. Kapany continued his work and in 1956 first applied the term "fiber optics" by defining fiber

optics as "the art of the active and passive guidance of light (rays and waveguide modes), in the ultra-violet, visible, and infrared regions of the spectrum, along transparent fibers through predetermined paths." (56)

During the ten year period from 1957 to 1967, interest and experimentation increased such that significant developments and applications were made in the following areas:

1. Waveguide mode propagation.
2. Coupling phenomenon in adjacent fibers.
3. The use of scintillating fibers for tracking high energy particles.
4. Skew ray propagation along fibers.
5. The use of fiber optics as field flatteners, Focons, and image dissectors in ultra-high-speed photography.
6. Extension of the spectral range of fiber optics in the infrared region.
7. Combining the field of lasers and fiber optics in lasing fibers, fiber amplifiers, hair trigger operation in fiber lasers, and light switching by waveguide "beating."
8. Application of fiber optics to various photoelectronics devices, data processing, and photocopying systems. In this field of photoelectronics

alone, fiber optics have been applied in multi-stage image intensifier coupling, high resolution cathode ray tubes, end window vidicons, and various forms of scan converters.

9. Application of fiber optics to the field of medicine: cardiac catheter assemblies to record and observe oxygen saturation of the blood; application of fiber-optic endoscopes for application to gastroscopy, bronchoscopy, rectroscopy, and cystoscopy; hypodermic probes; in vivo cardiac oximeter; laser coagulator for treatment of remote tissues using fiberscopes; scintillating fibers for radiology; endoscopes for the inspection of the pericardium, thoracic cavity, bone joints, living fetus and peritoneal cavity. (56) (82) .

However, before 1967, in the field of electronics, glass fibers were not seriously considered as a communications medium for transmission over even moderate distances (about 1 km) because of high attenuation losses associated with glass fibers.* Primary emphasis prior to 1968 was on image transmission devices of short length ($\ll$ 5m) and illumination devices.

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*Attenuation, or loss of light in a glass fiber, is expressed in terms of decibels per kilometer (dB/km). This subject will be discussed in more detail in Section III.

The first serious interest for communications was expressed by K.C. Kao of Standard Telecommunications Laboratories in England in 1968. At that time, technology was paced by the ability of industry to draw fibers of long length and low loss. (76)

In 1967-68, laboratories began development programs to develop low-loss fiber optics in response to inquiries from telecommunications laboratories. An attenuation level of 20 dB/km was set as an acceptable goal (Figure 1), since that level of performance was believed to be compatible with existing telecommunication systems configurations and would be sufficient to tip the economic scales in favor of optical waveguides. (10)

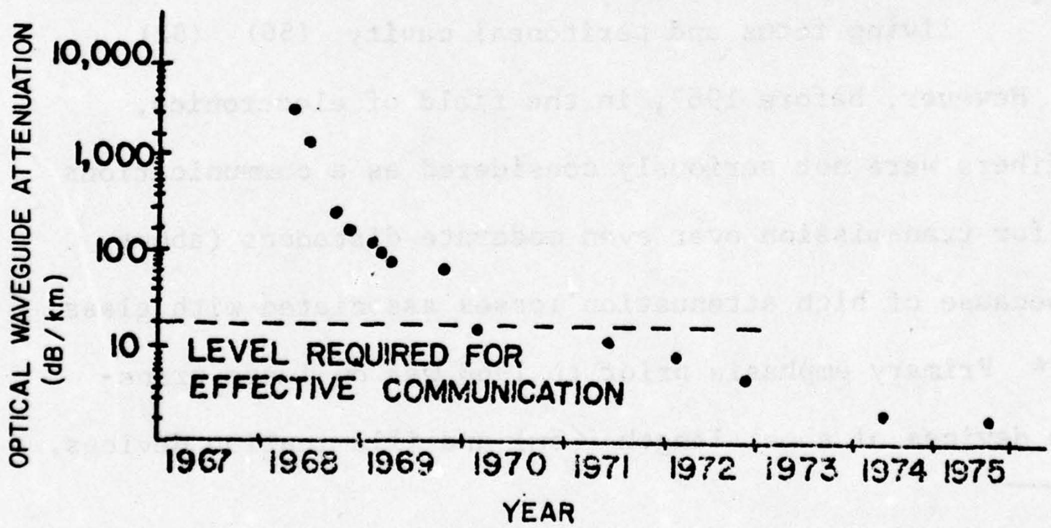

Figure 1 Historical progress in low-loss waveguides: lowest attenuation achieved vs. year

At that time the fiber optic communication technology, involving multimode fiber optic bundles and discrete semiconductor sources (light-emitting diodes, LEDs) and detectors (silicon positive intrinsic-negative diodes, PINs), received great stimulation and impetus from the announcement in November 1970 by Corning Glass Works of glass-fiber waveguides with 20 dB/km attenuation at a wavelength of 820 nanometers (nm). (Commercial-grade fibers up to that time had about 1000 dB/km attenuation). In 1971, Bell Laboratories developed liquid-core low-loss fibers with losses less than 20 dB/km out to 1100 nm. (80)

In August, 1972, the Corning Glass Works announced that they had surpassed the attenuation goals by developing fibers with an attenuation loss of 4 dB/km at wavelengths of 850 and 1060 nm. Losses between 600 and 900 nm were all below 12 dB/km. (10) By August 1974, Bell Labs had developed a fiber-optic cable with an attenuation loss of only 2 dB/km at 1060 nm. (8)

The development of low-loss fibers was not the only obstacle to overcome, however. Even the mundane problems of making connectors that worked and figuring out ways to repair a broken fiber in the field looked like serious roadblocks. There were so many problems as late at 1972 that few expected fiber-optic systems to find anything but specialized applications

until the 1990s. However, most of the earlier problems have been under parallel attack in dozens of laboratories around the world, most notably in Russia, Japan and western European countries. The stumbling blocks of 18 months ago have virtually disappeared. "This is one of the fastest-moving technologies I've ever seen," says Don Alexander, who monitors cable developments from International Telephone & Telegraph Corp.'s headquarters in New York. (60)

"A lot of things have come to pass in one and a half years instead of five," agrees Herbert A. Elion of Arthur D. Little, Inc., who has been working on optoelectronics since 1968. Elion, who has been working on fiber optics with a group of 27 clients from four continents -- both companies and government agencies -- says that spending for development efforts in fiber-optic systems topped $100 million in the past year (1974). He expects it to double in 1975-76. "People argue about the time scale," he says. "Some projects have been advanced from 1979 to 1976." (60)

Technologically, it appeared that it was feasible to use fiber optics in communication and data link systems. With unlimited potential for future application and the door already cracked, it only remained for both industry and the military to expend time, effort and money in research and development programs in order to start reaping the benefits offered by fiber optics.

APPENDIX B

The Fiber Optic Cable Industry

I. <u>INTRODUCTION</u>

Domestic production of fiber optic cable is slowly increasing as new applications are discovered for the cable. Technology breakthroughs are taking place at such a rapid rate, that technological possibilities for ten years hence are becoming realizable in two or three years. Such breakthroughs are generating interest among big names in the high technology fields. Organizations such as BELL Labs, RCA, GTE, CORNING Glass have moved into the research field. The impact of this interest in fiber optic cable is continual discoveries of additional uses and applications. As additional uses are found, an increased demand for fiber optic cable is generated which influences fiber optic cable producers to conduct further research and development. Research and development by fiber optic cable manufacturers then produces fiber optic cable with new characteristics which increase the interest for new applications. The demand for fiber optic cable increases, the "user/producer" loop is closed and the cycle continues.

This interest ... research ... production ... application cycle is self-generating and therefore a natural phenomenon which continues throughout the growth of a new and evolving technology. Analyzing such an infant industry (infant, but with fantastic potential) is a unique task since only limited data is available and a baseline or "benchmark" is non-existant.

A logical beginning to this analysis would be to define the industry being analyzed, however the fiber optic cable industry is not easily defined. The Standard Industrial Classification (SIC) manual(36) was searched for some key to defining the industry. In place of a definition, the SIC manual produced the questions:

(1) Is the fiber optic cable industry engaged in manufacturing flat glass and other glass products ... from materials taken principally from the earth in the form of stone, clay and sand, or

(2) is the fiber optic cable industry engaged in manufacturing ... optical instruments and lenses?

If one can assume that the answer to question number 1 is YES, then the fiber optic cable industry can be defined by the SIC 3229 (pressed and blown glass and glassware, not elsewhere classified - Fibers, glass). If though, question number 2 is answered YES, then the industry can be defined by the SIC 3832 (optical instruments and lenses - Fiber optical devices). After several interesting telephone interviews with persons engaged in the production of fiber optic cable, the authors have defined the fiber optic cable industry with the SIC 3229. To expand upon the SIC definition, the authors have defined the following:

(1) INDUSTRY - any domestic firm producing and marketing fiber optic cable. The firm may also be involved in Research and Development but it can be considered a part of the "industry" only if engaged in actual fiber optic cable production. This eliminates the problem of including pure laboratories as a part of the industry.

(2) FIBER OPTIC CABLE - optical cable having light energy propagation characteristics. Of primary concern is fiber optic cable capable of being used as an optical waveguide.

A composite definition of the fiber optic cable industry can be derived from the above definitions to form the boundries within which this analysis was conducted. The rationale for overlaying SIC 3229 and the authors' definitions above, was pure judgment applied to CAVES (15) analysis method of observing an industries charactristics of STRUCTURE, CONDUCT AND PERFORMANCE.

II. STRUCTURE OF THE FIBER OPTIC CABLE INDUSTRY

"Market structure is important because the structure determines the behavior of firms in the industry, and that behavior in turn determines the quality of the industry's performance." (15) Structure is therefore a prime ingredient of both Conduct and Performance. The fiber optic cable industry is not of sufficient size to significantly impact upon the market place. However due to the rapid advances in fiber optic technology, it does have the potential to become a significant contributor to the U.S. economic goals.

A. MAJOR PRODUCERS

A recent survey conducted by the Naval Electronics Laboratory Center (NELC), San Diego, California indicated that less than ten domestic firms are presently actively engaged in the production of fiber optic cable. These same firms are also pursuing research and development programs in order to both improve existing cable and develop

new types of fiber optic cable. Initially the figure of ten firms seemed small, but after several telephone interviews it was apparent that even with the wide spread interest in the uses of fiber optics, the actual consumption of fiber optic cable is relatively small. Competition between the major fiber optic cable producers is quite keen; this combines with the fact that fiber optics is a newly evolving infant technology, much of the data required for a thorough analysis remains proprietary and was not made available to the authors.

A few of the present fiber optic cable producers are:

(1) American Optical Corporation.
(2) Corning Glass Works
(3) Galileo Electro - Optics Corporation
(4) Valtec Corporation

This is not an all inclusive list, it is only those producers which were readily available as data sources.

B. PRODUCER/SELLER CONCENTRATION

Production and sales of fiber optic cable is an international effort. However, international sales and imports are not a significant portion of total domestic sales and use of fiber optic cable. Countries other than the United States that have shown keen interest in the advance of fiber optic technology are Europe, Russia, Japan and the United Kingdom. Since the international production and sales of fiber optic cable has an insignificant impact upon domestic production, there will be no further reference made to international producers.

Domestic production of fiber optic cable is divided into basically two types of products:

(1) <u>Light Guides</u> - lower quality fiber optic cable used to "guide" light from a light source to a destination. An application for light guides could be the automotive industry, where the fiber optic cable would be used for illumination and indicator lights.

(2) <u>Date Transmission Cables (optical waveguides)</u> - high quality low loss fiber optic cable used to carry data in the form of light energy. An application for data transmission cables, presently being researched, is telephone information transmission.

The present domestic demand for both light guides and data transmission cables is not large enough to impact upon producer/seller concentration. Based upon telephone conversations with several fiber optic cable producers, it appears that the domestic production of fiber optic cable is not shared equally among the few producers. An <u>unqualified</u> approximation, by the authors of the industry would be that 80 percent of the fiber optic cable prduced domestically is done so by 20 percent of the firms in production. An extensive search of all marketing data would be required to substantiate the concentration approximation but that effort was not feasible due to the lack of published data.

C. BARRIERS TO ENTRY

In order to lend credibility to the statement that 80 percent of the fiber optic cable produced domesticaly is done so by 20 percent of the firms in production, a detailed search for barriers to entry was conducted. The search

uncovered several interesting and relevant facts. These facts combined with knowledge of present producers facilities imply a certain validity to the concetration approximation plus point out barriers which would minimize the entry of new firms into the productic 1 of fiber optic cable.

1. Equipment Requirements

The equipment required to produce fiber optic cable is not readily available within the general production equipment market place. Any firm desiring to become a producer of fiber optic cable must either design and develop their own production equipment or use an equipment already in existence which was designed by a competitor already producing fiber optic cable. Since the production of fiber optic cable is still in the development stage, much required information on materials, equipments and procedures remains proprietary. Therefore the use of an existing equipment design is often times not possible and the primary method of obtaining production equipment is through an in-house research and development program.

The two basic types of fiber optic cable, (a) light guides and (b) data transmission cables each require a different production technique. This difference is particularly apparent in the quality control requirements of each cable type. Fiber optic light guides are the easiest of the two types to produce and requires only a moderate quality control program. The high quality data transmission cables requires very close tolerance production techniques

and the production equipment must be made highly responsive to quality control inputs. The quality control equipments in use today do not incorporate full automation. The implication of this lack of total automation in that there exists no automatic feedback loop to make required on-line changes to an on-going production process. In order to accomplish the required quality control feedback process, highly skilled on-line production personnel are required to form the feedback loop.

2. Personnel and Skill Requirements

A second major barrier to entry is the need for highly skilled personnel to produce fiber optic cable. This high skill level is required in both the research and development of (a) high quality cable types, (b) production equipment and (c) production procedures and the actual production of fiber optic cable. The personnel requirements for actual fiber optic cable production are separated into two phases.

Phase one is the initation of a production system. This is a major problem requiring integration of newly developed production equipment, raw material and procedures into an effective and efficient production line. During this phase, very highly qualified engineers and scientists are required to accomplish the task of proper integration and initial production.

Phase two follows after an effective and efficient production system has been established. At that time a team

of highly qualified technicans would receive on-the-job training and assume the responsibilities for production. Due to the lack of fully automated quality control equipment, the implementation of phase two is a major task.

It is interesting to note that information was received by the authors which implied that a certain fiber optic cable producer requires that engineers and scientists be on the production line in order to maintain the high quality required of data transmission cable.

The high cost of production equipment development combined with a shortage of well qualified personnel trained in fiber optic technology are, in themselves, two monumental barriers to entry into the production of fiber optic cable. Add to these two barriers, (1) the present relatively small demand for fiber optic cable, (2) the extreme high quality data transmission cable required by the research and development laboratories and (3) the state-of-the-art advances in data transmission cable requiring an in-house research and development effort and then the barriers to entry becomes quite formidable.

D. PRODUCT DIFFERENTIATION

Differentiating a fiber optic cable product line is tied directly to the availability of a dynamic in-house research and development effort and well qualified personnel. As the infant fiber optic technology expands and presses the state-of-the-art, it is imparative that a firm continually advance their product line. During the industries

formative years, it is the successful company that continually expands its product line to challenge the users to develop new and additional uses, through a dynamic research and development program. Being a new technology, the qualified personnel exist in a convulsive environment. This environment is caused by the keen competition required to anticipate and meet the ever changing demands of a basically research and development oriented market place. Creating a use for a new fiber optic cable is a key factor in successful infant technology product differentiation.

III. CONDUCT OF THE FIBER OPTIC CABLE INDUSTRY

"Market conduct consists of a firm's policies toward its product market and toward the moves made by its revals in the market."(15) An industries behavior in changing prices, outputs, product characteristics, selling expenses and research expenditures is primary market conduct.

The problem of proprietary data within the fiber optic industry surfaced again while attempting to uncover individual fiber optic cable producer operating philosophies. The convulsive nature of this evolving industry would suggest an unpredictable market conduct. However, this is not necessarily true. The few firms engaged in the production of fiber optic cable are aware of the problems faced by a potential entrant to the industry and existing firms act as an oligopoly.

A. PRICE POLICIES

An oligopolist may change his product prices at his own discretion in an attempt to capture a larger share of the market or possibly bluff competitor firms. If one firm has a highly differentiated product, other firms in the industry would be less sensitive to price changes. This appears to be a driving force within the fiber optic cable industry.

Product differentiation in the form of a higher quality cable than competitors can produce and at a low price, appears to be a firms prime goal. Because of this philosophy, fiber optic cable producers are spending a large sum annually on research and development. The magnitude of a firms research program is strongly dependent upon managements speculation of future market demand for the product. Among the few fiber optic cable producers, speculation is strong that the future demand for high quality cable will be great.

In an attempt to perpetuate the interest of potential future fiber optic cable users, the cable producers are conducting extensive research and development programs. The effect of these research programs has been an increase in fiber optic cable quality and a rapid reduction in price. If price reduction continues as it has over the past few years, the price of fiber optic cable will be less than that of a comparable copper wire type cable.

New uses developed for fiber optic cable potentially reduces the market for the present copper wire cable

industry. This could cause the copper wire cable industry to begin a price reduction strategy in competition with the fiber optic cable industry. If the copper wire industry began to vigorously compete with the fiber optic cable industry, this could have a strong impact upon both industries price policies.

B. PRODUCT POLICIES

As stated prior, one area of fiber optic research is in production methods, specifically quality control. A firm must make a decision to (1) maintain quality and price, (2) maintain quality and reduce price, (3) improve quality and maintain price or (4) improve quality and reduce price. Clearly alternative number (4) should be the most advantageous to a fiber optic cable producer. A unique feature of the fiber optic cable industry is the market is nearly all research oriented; it is a users market. There should be a point in time when fiber optic cable quality increases to a level acceptable for large scale use and at a price low enough to entice potential large scale users.

Assuming future large scale use of fiber optic cable, producers would then have more flexibility in product line, product quality and price. CAVES notes that, "the great majority of industries seem to be more independent (and less collusive) in their product policies than in their policies toward pricing. Price adjustments, far more often than product adjustments, seem to aim at protecting maximum joint profits for the industry." (15)

This thought would suggest that future high quality cable production would be of two types. Firms would mass produce "standard" fiber optic cable in large quantity and then also specialize in cable for specific application requiring a unique fiber optic technology base. Thus allowing a competition among firms for the production of "standard" fiber optic cable while maintaining a sufficient product differentiation to have a flexible product policy.

IV. PERFORMANCE OF THE FIBER OPTIC INDUSTRY

CAVES defines market performance as the appraisal of how much the economic results of an industry's market behavior deviates from the best possible contribution it could make to achieving these goals.(15) Restated, this means performance is how well an industry "performs" in relation to some standard of performance or economic goals. In general terms, economic goals would be (1) efficiency, (2) full employment, (3) progressiveness and (4) equitable distribution of real output among members of the industry.

It would indeed be valuable to evaluate the fiber optic cable industry in relation to these four economic goals. However, these goals are clouded by the lack of data and at best each goal can only be speculated upon by the author.

A. EFFICIENCY

Each firm producing fiber optic cable is attempting to improve both its technical and allocative efficiency. This

improvement is being attempted in the use of raw materials, production equipment/techniques, and manpower. Improved efficiency is one of the firm's research and development program goals and must be evaluated over the next few years as the industry expands. Using engineers and scientists on a production line to maintain quality control is not efficient and is an area for immediate improvement.

B. FULL EMPLOYMENT

The interaction between the industry and this goal is twofold. There exists today a requirement for skilled workers qualified in the production of fiber optic cable. Through research programs, production automation will eventually be attained, but then what happens to those people being trained and employed on today's unautomated production line? Will additional firms enter the industry and absorb the excess people? These are questions which will remain unanswered until sometime in the future.

C. PROGRESSIVENESS

Progressiveness can be equated to innovation and innovation has been the watch-word of the fiber optic cable industry. Rapid advances in fiber optic technology have come to be expected through dynamic research and development programs. An examination of financial statements did not uncover the key to the dollar value of research programs, but the advances appear to be concentrated within the top 20% of the firms. One firm, which desires to remain anonymous, has a

goal of "such high quality and low cost fiber optic cable that we will take over the world market." Now that is a positive progressive attitude!

D. EQUITABLE DISTRIBUTION OF REAL OUTPUT

The connection between industrial firms and the equity of the distribution of real output (income) is weak.(15) This is especially true of the fiber optic cable industry, since in most cases the production of fiber optic cable is only a very small percentage of the firms overall product line or business. There is no way to tell if due to the apparent concentration of firms that those few firms "on top" tend to earn greater profits than the remaining firms since there is no way to determine the profitability of the present fiber optic cable business.

V. SUMMARY

In summary, the fiber optic cable industry is an infant experiencing growing pains, unaware of, (1) what the future market demands will be, (2) what technological breakthroughs will be made by competitors, (3) what additional uses will be found for existing cable to name only a few complex problems. The industry appears to be filled with optimistic managers, engineers, scientists and technicians for they feel that the future is bright for the fiber optic cable industry.

APPENDIX C

A-7 Navigation Weapons Delivery System (NWDS) Schematics

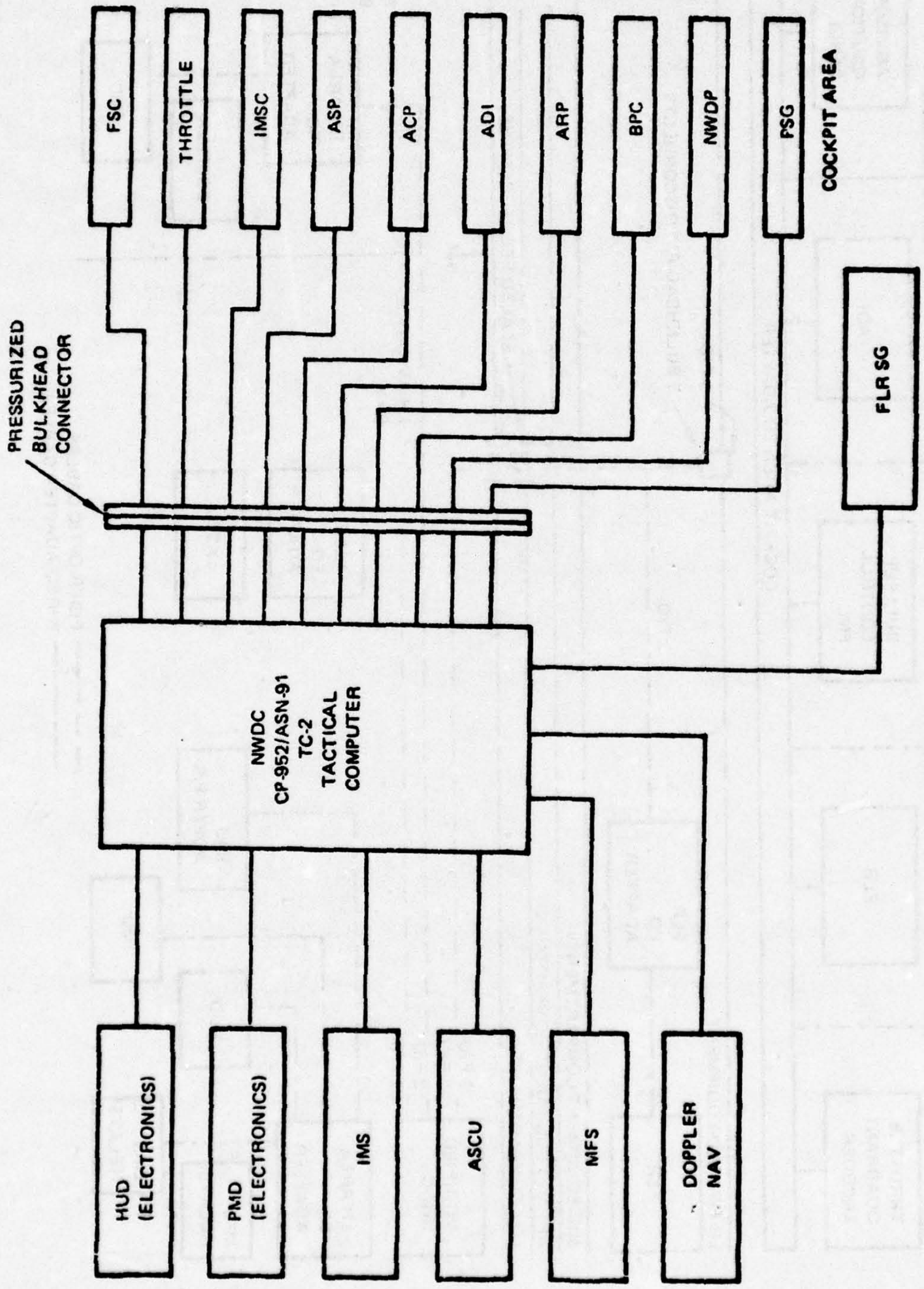

Figure 1. A-7 N/WDS electrical interface

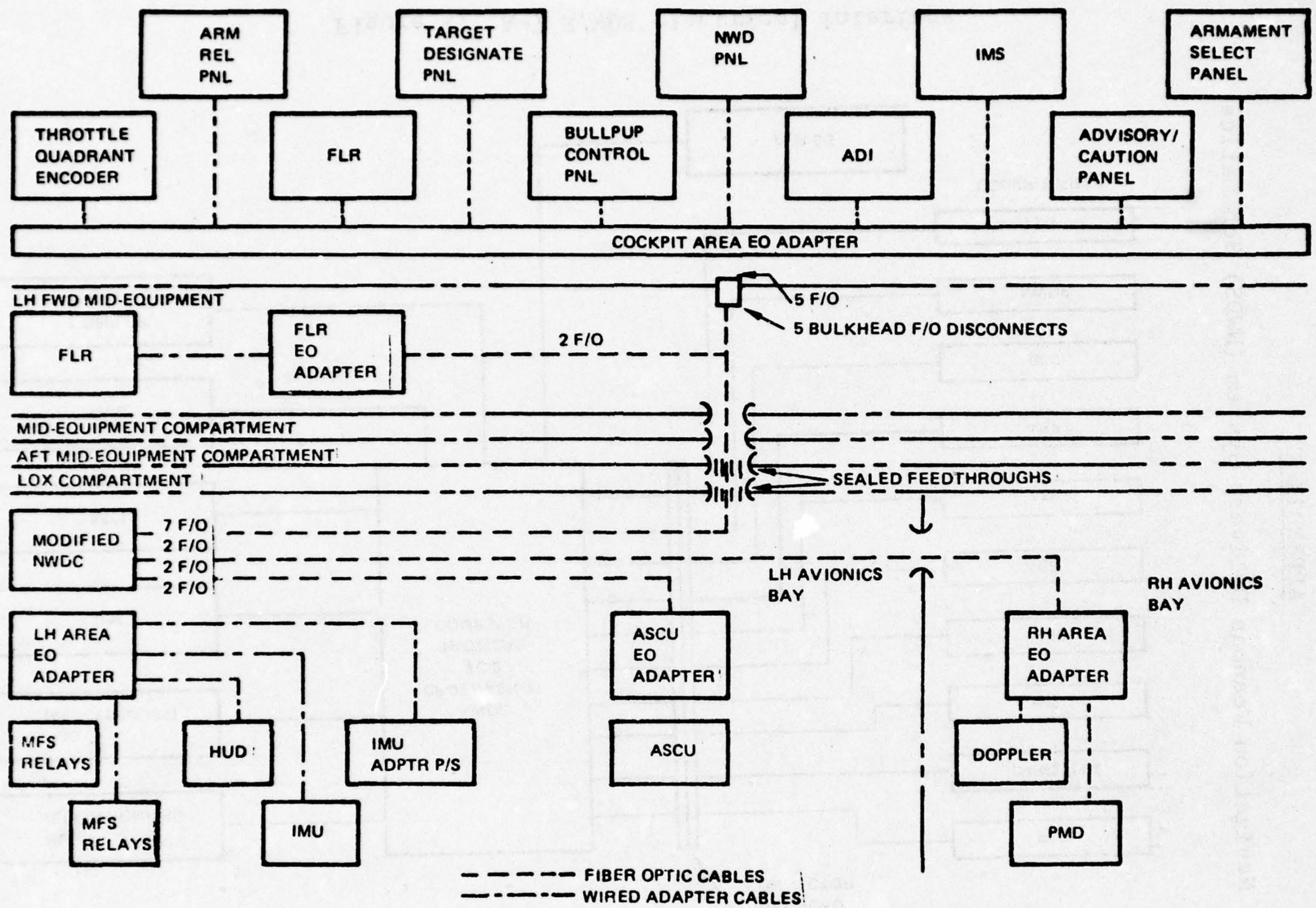

Figure 2. A-7 ALOFT system configuration.

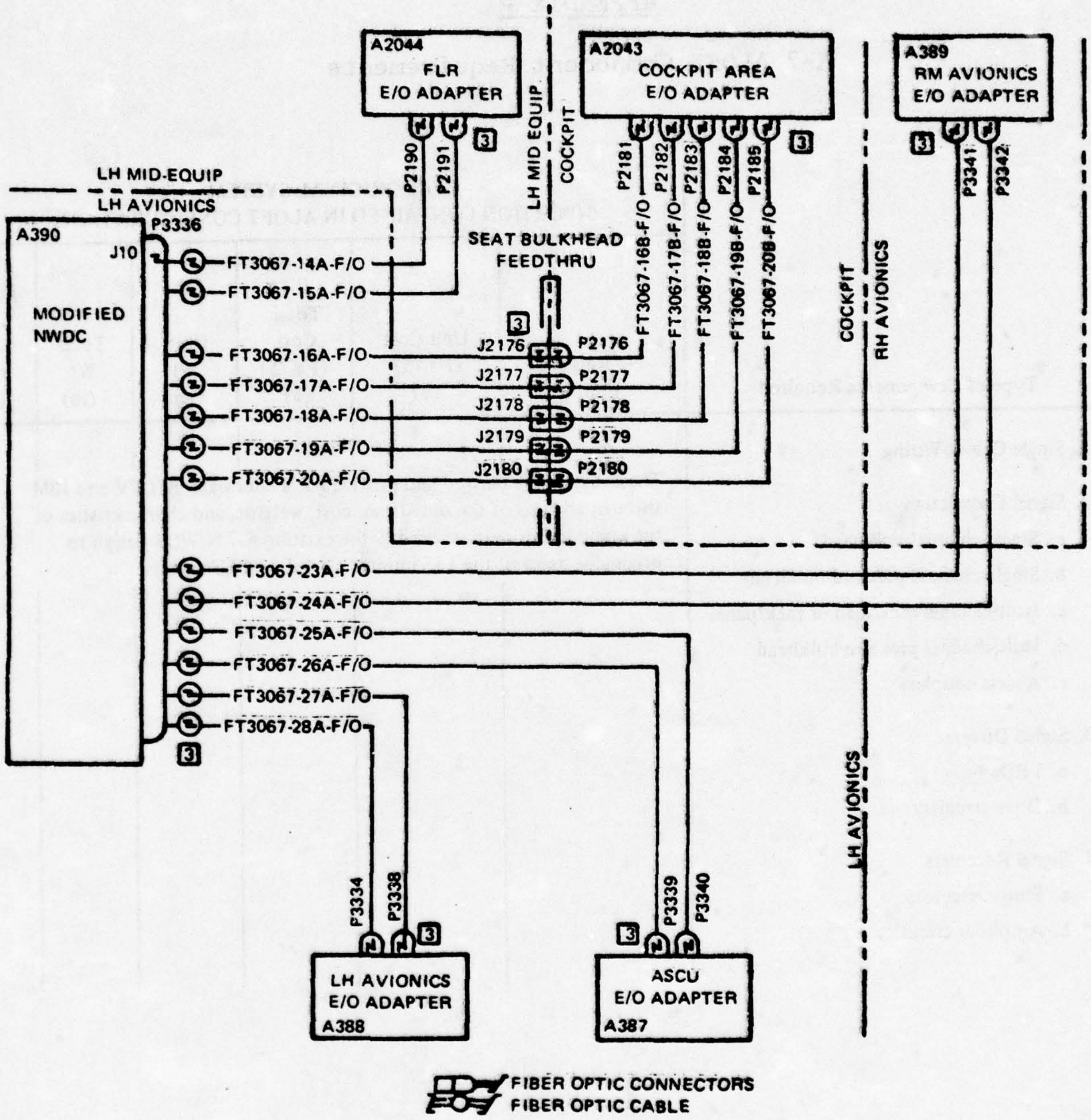

Figure 3. A-7 ALOFT fiber optic interface configuration.

APPENDIX D

A-7 ALOFT Component Requirements

Type of Components Required	A. ORIGINAL SYSTEM (PORTION CONTAINED IN ALOFT CONFIGURATION)					
	No Required Footage	Unit Cost (FY75) ($)	Total Cost (FY75) ($)	Unit Wt (gm)	Total Wt (lb)	Total Power Consumption (W)
1. Single Cables/Wiring						–
2. Signal Connectors	These data to be derived and provided at a later date by LTV and IBM through analysis of the quantities, cost, weights, and characteristics of the components that are used in the existing A-7 N/WDS design to originally transmit the 115 unmultiplexed ALOFT signals.					
a. Single-channel bulkhead						–
b. Single-channel pressure bulkhead						–
c. Multichannel bulkhead or rack/panel						–
d. Multichannel pressure bulkhead						–
e. Access couplers						
3. Signal Drivers						
a. LEDs						
b. Drive circuitry						
4. Signal Receivers						
a. Photodetectors						
b. Amplifier circuitry						

Source: NELC TD 435

Type of Components Required	B. TWISTED PAIR – AFTER MULTIPLEXING						
	Perform Req or Part No	No Required (footage) ($)	Unit Cost (FY75) ($)	Total Cost (FY75) ($)	Unit Wt (gm)	Total Wt (lb)	Total Power Con-sump-tion (W)
1. Single Cables/Wiring							
2. Signal Connectors							
a. Single-channel bulkhead	Determined to be infeasible with presently available twisted-pair components at 10-Mbit data rates and within MIL-E-5400P Class II Aircraft Environment.						
b. Single-channel pressure bulkhead							
c. Multichannel bulkhead or rack/panel							
d. Multichannel pressure bulkhead							
e. Access couplers							
3. Signal Drivers							
a. LEDs							
b. Drive circuitry							
4. Signal Receivers							
a. Photodetectors							
b. Amplifier circuitry							

C. COAX – AFTER MULTIPLEXING

Type of Components Required	Perform Req or Part No	No Required (qty/footage)	Unit Cost (FY75) ($)	Total Cost (FY75) ($)	Unit Wt (lb or gm)	Total Wt (lb)	Total Power Consumption (W)
1. Single Cables/Wiring	RG-316	13 (225 ft)	0.30/ft	66.08	0.012/ ft	2.7 lb	–
2. Signal Connectors							
a. Single-channel bulkhead	Sealectro 50-622-9188-31	36	3.27 ea	117.72	3.371g ea	0.21 lb	–
	50-645-4576-31	26	3.27 ea	85.02	2.320g ea	0.13 lb	
b. Single-channel pressure bulkhead	Sealectro 50-675-7000-31	5	8.34 ea	41.70	4.34g ea	0.05 lb	–
c. Multichannel bulkhead or rack/panel	–	0	No multichannel coax connectors considered feasible for this application. Single channel utilized instead with printed circuit board connectors.				–
d. Multichannel pressure bulkhead		0					
e. Access couplers	–	0	–	–		–	–
f. Printed circuit-board	Sealectro 50-651-0000	26	4.46 ea	115.96	2.320g ea	0.133 lb	–
3. Signal Drivers	SN54S140	13	6.26 ea	81.38		0.004 lb	0.286
a. LEDs	–	–	–	–	–	–	–
b. Drive circuitry	–	–	–	–	–	–	–
4. Signal Receivers	SN54S132	13	13.28 ea	172.64	ea		0.585
a. Photodetectors	–	–	–	–	–	–	–
b. Amplifier circuitry	–	–	–	–	–	–	–

D. FIBER OPTICS – AFTER MULTIPLEXING

Type of Components Required	Perform Req or Spec No Part No	No Required (qty/footage)	Unit Cost (FY75) ($)	Total Cost (FY75) ($)	Unit Wt (lb or gm)	Total Wt (lb)	Total Power Consumption (W)
1. Single Cables/Wiring		13 (225 ft)	2.50/ft	562.50	6.94/ft	3.42	–
2. Signal Connectors	See NELC Performance Requirements Sheets in appendix A for description of required components						
a. Single-channel bulkhead		13	2.50 ea	32.50	13.56g ea	0.389 lb	–
b. Single-channel pressure bulkhead		5	3.50 ea	17.50	22.79g ea	0.251 lb	–
c. Multichannel bulkhead or rack/panel		1	500.00 ea	500.00	255.00g ea	0.562 lb	–
d. Multichannel pressure bulkhead		0					
e. Access couplers		0					
3. Signal Drivers		13 (12 digital & analog					4.45
a. LEDs		a. 14*	80.00 ea	1120.00	**	**	–
b. Drive circuitry		b. 12 digital	2.50 ea	30.00g	0.085 lb		–
		1 analog	32.00 ea	32.00g	0.027 lb		–
4. Signal Receivers		13 (12 digital 1 analog)	--	–	–	–	6.31
a. Photodetectors		a. 14*	38.25	535.50	**	**	–
b. Amplifier circuitry		b. 12 digital	50.84	610.08	17.5g	0.463 lb	–
		1 analog	31.85	31.85	16.25g	0.036 lb	–

*The one analog link in the ALOFT design requires two LEDs: one direct signal transmission and one for feedback for linear compensation. Therefore, the transmission over 13 data channels requires 14 LEDs and 13 photodetectors.

**The weight figures for driver circuitry and amplifier circuitry include the weights of the LED and photodetector, respectively.

APPENDIX E

A-7 ALOFT Component Descriptions

Description of Components Required as Building Blocks for a Point-to-Point Information Transfer System of 115 digital signals (A-7 ALOFT baseline):

A. Coax Interface System Components Requirements (assuming digital transmission only over 13 data links – no analog). Prices in quantities (FY75 prices).

1.0 CABLE. Type RG316

Spec: (Description) 50Ω, 0.102″ OD, 29.4 pF/ft, loss = 3.8 dB/100 ft @ 10 MHz, temp = –55 to +200°C

Requirement: 225 feet

Price: $293.70 per 1000 feet; $66.08 total system cost

Weight: 0.012 lb/ft; 2.7 lb total system

2.0 CONNECTORS

2.1.1 Terminal Connectors. Type Sealectro 50-622-9188-31. All connector prices subject to 10-percent gold surcharge

Spec: Crimp type coax connector – straight plugs for RG316. All connector specs MIL-C-39012 SMA

Requirement:	2 ea for each cable link (13)	26
	2 ea for each bulkhead connector =	10
	Total	36 each

Price: $3.27 each; $117.72 total system cost

Weight: ~3.371g each

2.1.2 Bulkhead Receptacles. Type Sealectro 50-645-4576-31

Spec: SMA receptacle MIL-C-39012

Requirement: 26 each (on each adapter unit, 2 for each cable)

2.2 Pressure Bulkhead Connectors. Type Sealectro 50-675-7000-31

Spec: MIL-C-39012 SMA

Source: NELC TD-435

Requirement: 5 each

Price: $8.34 each/$41.70 total

Weight: ~4.340g each

2.3 No multichannel connectors.

2.4 PC Card to Coax Connector. Type Sealectro 50-651-0000

Spec: MIL-C-39012 SMA

Requirement: 26 each

Price: \$4.46 each/\$115.96 total

Weight: ~2.320 grams

3.0 LINE DRIVERS. Type SN 54S140

Spec: Dual line drivers, 50Ω, Schottky for operation at 10 MHz

Requirement: 13 each (assume only one gate used per IC)

Price: \$6.26 each/\$81.38 total

Power: 22 mW ea/gate; 0.286W total

Weight: ~ 1.973 grams each

4.0 LINE RECEIVERS. Type SN 54S132

Spec: Quad Schmitt trigger

Requirement: 13 each

Price: \$13.28 each/\$172.64 total

Power: 45 mW ea gate; 0.585W total

Weight: ~ 1.973 grams each

B. Twisted-Pair Interface System Components Requirements

Conclusion reached after searching for qualified components that twisted-pair interface not possible. Components for 10-megabit data rate did not readily exist. RG-108 could have been used if constraint of MIL-E-5400P Class 2 environment had not been a requirement. RG-108 is only good for –40 to +80°C temperature range which is below Class 2.

C. Fiber Optic Interface System Components Requirements

1.0 FIBER OPTIC CABLE PERFORMANCE REQUIREMENTS

1.1 Number of fibers: 367 – 1 percent (4)

1.2 Number of broken fibers: four if unterminated; seven if terminated

1.3 Fiber diameter: 0.00215 inch

1.4 Core glass area to total fiber area ratio: ⩾85 percent

1.5 Numerical aperture: between 0.54 and 0.67

1.6 Maximum optical attenuation: 400 dB/km

1.7 Cable jacket and shield to be nonmetallic

1.8 Termination diameter: if terminated, active area diameter to be 0.0455 inch

1.9 Termination loss: without lenses or refraction matching, throughput loss to be <2.0 dB

1.10 Environmental range: temperature, temperature shock, vibration, mechanical shock, and altitude capabilities to conform to MIL-E-5400P Class 2

1.11 Mechanical requirements: impact, bending, and twisting to conform to MIL-C-13777F

1.12 Tensile strength: 35 lb

2.0 SIGNAL CONNECTOR PERFORMANCE REQUIREMENTS

2.1 Fiber Optic Cable: Fiber optic cable used with connectors to be as required in performance requirements for fiber optic cable

2.2 Termination Diameter: Connector termination for fiber optic cable to be 0.0465 (+0.001) inch diameter

2.3 Cable Retention: Connector retention to exceed breaking strength of glass

2.4 Optical Loss: Maximum optical throughput loss to be ≤ 2.75 dB measured at 800 to 950 nm

2.5 Environmental Requirements: Temperature, temperature shock, vibration, mechanical shock, and altitude capabilities to conform to MIL-E-5400P Class 2

2.6 Connector Durability: All requirements met after 1000 cycles of mating and unmating

2.7 Pressurization: Connectors designed for use as pressure bulkhead penetrators to meet pressurization requirements of MIL-E-5400P Class 2. Also to maintain required gage pressure of 30 (±5) psi during steps 2 and 12 of MIL-T-5422 for Class 2 operation

2.8 Requirements apply to single-channel and multichannel connectors

3.0 DIGITAL SIGNAL DRIVER PERFORMANCE REQUIREMENTS

3.1 Electrical: Input to ITTL load; power supply to be 5.0 (±0.5) Vdc

3.2 Optical Output: Optical half-power points to be 50 nm apart and within range of 800 to 950 nm

3.3 Power Coupling Ability: 1.25 mW into 45-mil-diameter fiber optic cable

3.4 Logic Code: 1.25 mW into 45-mil cable at application of high TTL input; ≤ 0.01W into 45-mil cable at application of low TTL input

3.5 Pulse switching time: ≤ 10 ns

3.6 Environmental Characteristics: Operate in all conditions of MIL-E-5400P Class 2 environment

3.7 Operation Lifetime: 10 000 hours continuous at 25°C

4.0 DIGITAL SIGNAL RECEIVERS

4.1 Responsivity: Platform 600 to 1100 nm

4.2 Power Supply: +5 (±0.5) Vdc and −5 (±0.5) Vdc

4.3 Transfer Characteristics: Convert input optical signals to standard TTL output format with fanout of 10. See following table:

Radiant Power Input (watts)		Power Supply (Vdc)	Electrical Output	
Min	Max		Min	Max
4×10^{-7}	2×10^{-4}	+5 (±0.5)	2.7 V @ 1-mA output current	
	2×10^{-8}	−5 (±0.5)		0.5 V @ 16-mA output current

4.4 Electrical Output Switching Time: ≤10 ns

4.5 Environmental Characteristics: Operate in all conditions of MIL-E-5400P Class 2

4.6 Operation Lifetime: 10 000 hours continuous at 25°C

APPENDIX F

Fiber Optics Cost Data Collection

Mfg	Loss	Dia (active)	Packing Fraction	NA	Fiber Dia.	No. of Fibers	Price/ft.
Galileo K2/K	0.15 dB/ft (457 dB/km) (0.21 dB/ft) (measured) [87m or 266ft/ 40dB]	45 mil, 1.125 mm	0.75	0.66			$2.50 mono-coil/pvc
American Optical M-80	0.122 dB/ft (372 dB/km) [108m or 328ft/ 40dB]	50 mil, 1.25 mm	0.80	0.55			$3.75 mono-coil/vinyl
Valtech	0.20 dB/ft (610 dB/km) [65m or 200 ft/40dB]	53 mil, 1.325 mm	0.88	0.56			$2.65 mono-coil/pvc (with termination)
Corning	6.5 dB/1000 ft (20 dB/km) [2km or 6096 ft/40dB]					7 19 37 61	$ 7/ft 19/ft 37/ft 61/ft ($1/ft/ fiber)
Pilkington	0.033 dB/ft (100 dB/km)		0.85	0.50			(<300 m, <900 ft.) (>2.5km)
100A		30.4mil 0.76mm	--		85mm	61	? ?
100B		23.2mil 0.58mm	(Re-		65mm	61	3.10ft 2.30ft
100C		18 mil, 0.45mm	fractive		65mm	37	2.22ft 1.76ft
100D		12.8mil 0.32mm	Index difference 0.048)		65mm	19	1.37ft 1.00ft

Preliminary Data Sheet on Fiber-Optic Cable Costs
Source: T. Meador, NELC

Manufacturer and Part #	P_{out} at 50 MA	V_f at 50 MA	Emission pattern Characteristics	Distance Emitting surface to exit	Emitting Area	Price	Comments
TI SL1282	600 μw	1.5Vmax	Lambertian		63mm^2/18 mil dia	$22.00	T1XL 12 packa
SL1314-5	600 μw	1.5V	.5 mw in 23° half angle		"	$21.00	T1L23,24 pack
TIXL 471	1.0 mw	1.5	Lambertian	5 mils	"	$35.00	
Spectronics							
SE1527	1.7 mw	1.5	>50% of power is in 25° half angle cone	30 mils	63mm^2/18 mil dia	$29.50	
SE1775	1.7 mw	1.5	>75% of power is in 25° half angle cone	50 mils	"	150.00	
Meret							
TL-25	1.0 mw	1.3	150° Lambertian	50 mils	20 mil sq	$9.40 + set up $ for package	Chopped TO-5 or 18; no se up for non-hermetic

Preliminary Data Sheet on LED Costs
Source: T. Meador, NELC

Device	Active Area(mm^2)	Irradiance Resp. at .910 μm A/W	Idc at 5V	C_{junct} at 5V	Distance Active Area to Radiance Entrance	Package	Reverse Breakdown Voltage	Cost/unit (50 units)
H. P.								
5082-4207	.8/40 mil dia	.25 A/W	<2500pa	6pf	75 mil	TO-18	20V	$ 36.30
UDT								
PIN 3D	50 mil dia	.26 A/W	20na	20pf	90 mil	TO-46	50V	9.65
PIN 040B	.8/40 mil dia	.26 A/W	4na	20pa	80 mil	TO-18	25V	18.00
Inotech								
PD050F	50 mil^2	.26 A/W	15na	7pf		TO-18	20V	10.00
EG+G								
SGD-040	.8/40 mil dia		<10na	<3pf	90 mil (A) 150 mil (B)	TO-5 (A) TO-46 (B)	200V	15.00 (A+B)
Motorola								
MRD510		.25 A/W	250pa	<4pf	180 mil	TO-18	100V	
Spectronics								
SD5425-1		.5 A/W	<20na	<4pf	185 mil	TO-46	75V	4.00
SD5425-2		.5 A/W	<20na	>4pf			200V	8.65
SPX1615	50 mil dia	.5 A/W	< 1na	>2.5pf		TO-46	>200V	22.00
Monsanto								
MDL	.58/34 mil dia	4.0MA/mw/cm^2	200na	15pf	> 150 mil	T046	50V	5.35
TI								
TIXL 80	.8/40 mil dia							NA

Preliminary Data Sheet on Silicon Photodiode Costs
Source: T. Meador, NELC

Company	Quantity of Fibers in Bundle	Bundle Diameter (inch)	Attenuation (dB/km)	Cost ($/ft)
Galileo	High Loss:			
	300	0.045	750+	0.11
	2,000	0.125	750+	0.82
	Medium Loss:			
		0.035	400	0.75
		0.125	400	3.00
Corning	High Loss:			
		0.087	1,000	.35
		0.120	1,000	.69
		0.129	1,000	.92
		0.139	1,000	1.15
	Low Loss:			
		0.050	30	17.50

A Comparison of Commercially Available
Multimode Fiber-Optic Cable
Source: Army REPORT EMCOM-4271 by CW3 Richard D. Parent
Nov. 1974

	ITEM DESCRIPTION	PRICE
1	P.V.C. Jacketed 35 mil dia fiber-optic cable	$0.75/ft
2	End terminator for TO 18 Mating	50.00
33	End terminator for TO 5 Mating	50.00
4	Hybrid, TO packaged, receiver in connector	400.00
5	Hybrid, TO packaged, transmitter in connector	350.00
6	Complete 100-foot long Hybrid System (Complete fiber-optic data transfer system including: end connector with LED, end connector with photodiode and amplifier, and 100 feet of 15 dB/km fiber-optic cable. This does not include power requirements.)	900.00
7	LED mounted in TO 18 size connector	50.00
8	SPD mounted in TO 18 size connector	50.00

Cost Breakdown of a Fiber-Optic Data Transfer System
manufactured by Galileo Electro Optics Corporation,
Galileo Park, Sturbridge, Mass., 0158
Source: Army REPORT EMCOM-4271 by CW3 Richard D. Parent
Nov. 1974

General Cost Information

COMPONENT			SOURCE
Fiber-optic cable	1.	The Valtech Corporation revealed in August 1975 that they have developed a commercially available 40 dB/km fiber-optic cable with 1 to 40 fibers. Prices range from $2/ft for the single fiber cable to $12.	Telephone conversation with LCDR JOHN ELLIS, Code 1640, NELC, 9-2-75
	2.	NELC accepted delivery of medium-loss (590 dB/km) multimode (367 fibers) fiber-optic cable at a cost of $2.50/ft. This is the cabling to be used in the A-7 ALOFT Demonstration.	Telephone conversation with LCDR JOHN ELLIS.
	3.	Galileo's K2K medium-loss (<500 dB/km) multimode cable is selling at $0.75/ft. Lower prices would be considered for quantity purchases of 100,000 ft.	Telephone conversation with Mr. Rodney Anderson, Galileo, 8-18-75
	4.	Corning's single mode (7-single mode fibers per cable) cable, CORGUIDE, is selling for $13.50/ meter, or about $4.11/ft.	Telephone conversation with Mr. Robert Freiberger, Corning Glass Works, 8-18-75
Drivers/ Receivers	1.	Discrete circuit drivers/ receivers for the A-7 ALOFT Demonstration cost approximately $110-120 each.	NELC TD-435
	2.	NELC has awarded a contract to Sperry Univac for the delivery of 60 Hybrid module receivers at a cost of $54,000 (i.e., $900 each). NELC has the option to obtain an additional 30 receivers at $285 each.	Telephone conversation with LCDR JOHN ELLIS, 2 September 1975
Connectors	1.	The ITT Cannon 13-channel bulkhead connector cost was $500 each (6 made). Subsequent cost has been reported as $50 each (unconfirmed).	Telephone conversation with LCDR JOHN ELLIS
	2.	Sealectro has provided NELC with single-channel bulkhead connectors at $2.50-3.50 each for use in the A-7 ALOFT Demonstration	NELC TD-435

APPENDIX G

Industry Contacts for Fiber Optics Components

NELC contacted the following list of manufacturers by mail or telephone. The representatives on this list were considered to have candidate components for the A-7 ALOFT demonstration. Some manufacturers do not appear on the tables in the text because their component seemed unlikely to exhibit the desired performance. Omission from the following list means only that there was no response from the manufacturer to an initial contact by NELC.

Source: NELC TD-426

FIBER OPTIC CABLES

American Optical Corp 14G Mechanic Southbridge, MA 01550	Walt Sigmund	(617) 875-9711
Ealing Optics Corp 2225 Massachusetts Ave Cambridge, MA 02140	Henry Murphy	(617) 491-5870
Edmund Scientific Co 101 E. Gloucester Pike Barrington, NJ 08007		(609) 547-3488
Fiberphotics 2257 Soquel Dr Santa Cruz, CA 95060	Bill Zinky	(408) 475-5242
Galileo E/O Corp Galileo Park Sturbridge, MA 01518	Rod Anderson	(617) 347-9191
Corning Glass Works Corning, NY	Rich Cerney Bob Freiberger	(607) 974-8788
ITT Electro-Optical Products Division Box 7065 Roanoke, VA 24019		(703) 563-0371

Valtech Corp 99 Hartwell St West Boylston, MA 01583	Welty Trout	(617) 835-6082

LEDs

Fairchild Microwaves Optoelectronics Div 4001 Miranda Ave Palo Alto, CA 94303	Don Staub Bruce Cairns	(415) 493-3100
General Electric Corporate R&D 1 River Road Schenectady, NY 12345	Jack Kingsley	(518) 346-8771
Litronix, Inc 1900 Homestead Rd Cupertino, CA 95014	Tony Heinz	(408) 257-7910
Meret, Inc 1050 Kenter Ave Los Angeles, CA 90049	Dave Medved	(213) 828-7496
Monsanto Electronic Special Products 3400 Hillview Ave Palo Alto, CA 94304	Grant Riddle	(408) 257-2140
Motorola Semiconductors Box 20912 Phoenix, AZ 85036	Francis Christian	(602) 962-3186
RCA Indl Tube Div Dept G New Holland Ave Lancaster, PA 17604	Jim O'Brien	(717) 397-7661
Spectronics, Inc 541 Sterling Dr Richardson, TX 75080	J. R. Biard	(214) 234-4271
Texas Instruments Mail Station 12 PO Box 5012 Dallas, TX 75222	Gene Dierschke	(214) 238-4561

PHOTODIODES

EG&G, Inc 35 Congress St Salem, MA 01970	Ed Danahy	(617) 745-3200
Fairchild Microwave & Optoelectronics Div 4001 Miranda Ave Palo Alto, CA 94303	Bruce Cairns	(415) 493-3100
Hewlett Packard 620 Page Mill Road Palo Alto, CA 94303	Hans Sorenson Stan Gage	(415) 493-1212
Inotech 181 Main St Norwalk, CT 06851	Ray Pennoyer	(203) 846-2041
Monsanto Electronics Special Products 3400 Hillview Ave Palo Alto, CA 94304	Wayne Stewart	(415) 493-3300
Motorola Semiconductors Box 20912 Phoenix, AZ 85036	Dave Durfee	(602) 244-4556
Quantrad Corp 2261 G S Carmelina Ave Los Angeles, CA 90064	Frank Ziemba	(213) 478-0557
RCA Indl Tube Div Dept G New Holland Ave Lancaster, PA 17604	Jim O'Brien	(717) 397-7661
Spectronics, Inc 541 Sterling Drive Richardson, TX 75080	J. R. Biard	(214) 234-4271
Texas Instruments PO Box 5012 Dallas, TX 75222	Ed Harp	(214) 238-3274

UDT, Inc 2644 30th St Santa Monica, CA 90905	Don Dooley	(213) 396-3175

CONNECTORS

Amphenol Connector 2801 South 25th Ave Broadview, IL 60153	Don Warenburg	(312) 345-9000
Deutsch Co Elect Components Div Municipal Airport Banning, CA 92220	Ted Alsworth	(714) 849-6701
ITT Cannon 666 E Dyer Road Santa Ana, CA 92702	Ron McCartney	(714) 557-4700

APPENDIX H

Fiber Optic Industry Delphi Questionnaire

PARTICIPANT IDENTIFICATION

Organization
or
Firm Name ____________________

Participant
Name ____________________ Position
Title ____________

Business ____________________

Address ____________________ Phone
No. ____________

Years in
Present
Position ________

Years in
Present
Occupation ________

Years
in the
Industry ____

Would you be willing to discuss the questionnaire with an interviewer? ( ) Yes ( ) No

PARTICIPANT SELF-RATING ON QUALIFICATIONS TO ANSWER IN AREAS OF INTEREST (1), HIGHLY QUALIFIED TO (5), POORLY QUALIFIED

Self-rating	#	BASIC EVENTS (including assumptions)	User desirability: Necessary - definitely needed now	Will be necessary soon	Desirable now, but not necessary	Will be desirable soon	Undesirable now, possibly desired later	Cannot forsee any desirability in future	Producer feasibility: Highly feasible - could produce now	Feasible - could produce in future	Likely to be produced very soon	Likely to be produced in future	Unlikely, but possible to be produced	Cannot forsee possibility of production	Probable timing (Enter the year by which you feel the probability is P that the named event will have occured): P=.20	P=.50	P=.90
(3)	A	(EXAMPLE: AVIONICS COMPUTERS IN MILITARY AIRCRAFT ARE MINIATURIZED TO 1/4 THEIR PRESENT SIZE).			X							X			1985	1992	2000
		------FIBER OPTICS TECHNOLOGY---------															
( )	1	Modular drivers/receivers, utilizing LED & PIN type diodes, etc., are in production and considered as off-the-shelf items. More than two companies are in competition for contracts. No monopolies.															
( )	2	Monolithic integrated optical circuit drivers & receivers are off-the-shelf available. (etc., as in above question).															
( )	3	MULTI-CHANNEL "STAR", etc., type connectors are off-the-shelf available. (etc., as in event 1).															
( )	4	SINGLE CHANNEL TRUNK, "T", CONNECTORS are in production as off-the-shelf items. (etc., as in event 1).															

PARTICIPANT SELF-RATING ON QUALIFICATIONS TO ANSWER IN AREAS OF INTEREST (1), HIGHLY QUALIFIED TO (5), POORLY QUALIFIED

	#	EVENT	User desirability: Necessary - definitely needed now	User desirability: Will be necessary soon	User desirability: Desirable now, but not necessary	User desirability: Will be desirable soon	User desirability: Undesirable now, possibly desired later	User desirability: Cannot forsee any desirability in future	Producer feasibility: Highly feasible - could produce now	Producer feasibility: Feasible - could produce in future	Producer feasibility: Likely to be produced very soon	Producer feasibility: Likely to be produced in future	Producer feasibility: Unlikely, but possible to be produced	Producer feasibility: Cannot forsee possibility of production	Probable timing (Enter the year by which you feel the probability is P that the named event will have occured): $P=.20$	Probable timing: $P=.50$	Probable timing: $P=.90$
		------FIBER OPTICS PRICE TO USER------															
( )	5	Multimode fiber-optic cable, low-loss (<50dB/km), designed to meet cable performance requirements, purchased in 10,000 foot lots, will cost: (Assume full production mode, several competing manufacturers, etc.) A. 40-50¢/ft (constant 1975 $'s)... B. 30-40¢/ft (constant 1975 $'s)... C. 20-30¢/ft (constant 1975 $'s)... D. 10-20¢/ft (constant 1975 $'s)... E. Other															

PARTICIPANT SELF-RATING ON QUALIFICATIONS TO ANSWER IN AREAS OF INTEREST (1), HIGHLY QUALIFIED TO (5), POORLY QUALIFIED

Enter the year by which you feel the probability is P that the named event will have occured

	#	EVENT	User desirability						Producer feasibility						Probable timing		
			Necessary - definitely needed now	Will be necessary soon	Desirable now, but not necessary	Will be desirable soon	Undesirable now, possibly desired later	Cannot forsee any desirability in future	Highly feasible - could produce now	Feasible - could produce in future	Likely to be produced very soon	Likely to be produced in future	Unlikely, but possible to be produced	Cannot forsee possibility of production	$P=.20$	$P=.50$	$P=.90$
		---FIBER OPTICS PRODUCTION (DEMAND)---															
( )	6	Total U.S. production of low-loss (<50dB/km) single mode fiber optic cable will be:															
		A. 1,000,000 feet															
		B. 10,000,000 feet															
		C. 100,000,000 feet															
		D. other															
( )	7	Total U.S. production of multimode (>200 fibers) medium loss (100-500dB/km) cable will be:															
		A. 1,000,000 feet															
		B. 10,000,000 feet															
		C. 100,000,000 feet															
		D. other															

APPENDIX I

PRELIMINARY COST ELEMENT DATA COLLECTION

I. PURPOSE

This report is a summary of the data collected as a follow-on effort to the procedures recommended in Volume Two of this report.

Volume Two developed a cost model to determine the differential or relative cost difference between specific aircraft signal wiring consisting of either coaxial cable or fiber optic cable. It then recommended an industry survey, specifically using the Delphi technique, to gather both actual and predicted cost data for signal wirings consisting of fiber optic cable and related fiber optic components.

II. SCOPE

The scope of this effort was limited to gathering cost data for 28 cost elements initially identified and subsequently reduced to 20 cost elements by mutual agreement between the Naval Electronics Laboratory Center and the authors.

The data gathered during this effort was not evaluated at this time. McDonnell Aircraft Company, St. Louis, Missouri, has been tasked by the Naval Electronics Laboratory Center to evaluate this data, using the NPS thesis cost model. The results of this evaluation are due by July 1976 and can be obtained from the Naval Electronics Laboratory Center, Code 235, San Diego, California, 92152.

III. PROCEDURE

Initial data gathering was to be conducted with the use of Delphi questionnaires developed within the NPS thesis. Due to the convulsive nature of the new fiber optic technology and the inherent limitations of the Delphi technique the authors chose to combine the Delphi technique with both telephone interviews and personal contact.

Appropriate Delphi questionnaires, taken from Appendices H and L, were distributed to both the aircraft and fiber optic manufacturers. Telephone and personal interviews were then conducted with both industries and other organizations as appropriate to finalize the data gathering.

When conducting any type of survey, individual bias can be a large factor. This bias was considered during the data gathering and minimized as much as possible. However, identifying bias of a respondent was subject also to interpretation and bias of this author. This subjectivity must be considered when evaluating the cost data presented in Table 1.

IV. RESULTS

Fiber optics, being an infant technology, has inherent subjectiveness in nearly all accumulated cost data. The fiber optic state-of-the-art is rapidly advancing, thus causing event the most accurate estimate to be only a "best guess." All cost data presented within this report is considered as "worst case" and subject to refinement over time.

Cost data has been summarized in Table 1 with amplifying remarks where appropriate. Except where noted, the cost number (in column 3) is the fiber optic cost relative to the cost of "equal functions" performance if using coaxial cable. Note the cost element 1.2.1.2, Design Engineering. The cost number value of 0.80 signifies that the estimated aircraft design engineering cost using fiber optic technology would be only 80 percent of the design engineering cost using coaxial cable technology.

Cost elements 1.2.1.4, 1.2.1.5, 1.2.1.8, 2.1.6.3.2, 2.2.2.3.4 and 2.2.2.3.3 are not applicable to coaxial cable technology. Therefore, the cost number associated with these six cost elements are estimated actual dollar values.

FY 76 was used as the cost data baseline for all but three cost elements. With the exception of cost elements 2.1.5, 3.1.2.1 and 4.2.2.3 all cost data has been expressed in terms of FY 76 dollars.

Cost elements 2.1.5 and 3.1.2.1 have been expressed in terms of FY 80 dollars. This was done because of an original assumption that a newly designed aircraft using fiber optic technology would begin production in FY 80. Cost element 4.2.2.3 was expressed in terms of FY 85 dollars. The rational here was that assuming a ten year aircraft economic life, estimated spare parts requirements would be based upon FY 85 dollars or an average of a ten year spare parts requirement.

Table 1 has been organized by cost data source rather than in order of cost element number. Primary cost data sources were aircraft

manufacturers and fiber optic cable/component manufacturers. U. S. Navy school commands supplied data cost element 2.2.2.2 and the remaining cost element values were calculated using Cost Estimating Relationships (CER) developed within the NPS thesis.

V. COMMENTS.

Few books have been written on the subject of cost estimating in new technologies, but each warns of the potential problems and hazards faced by someone venturing into a new filed looking for non-existent data. Cost data in the field of fiber optics is no exception; it exists today only in limited form and many times is considered as proprietary.

The field of fiber optics today is infantile and the future is speculative at best. There is no high demand for quality fiber optic cable or associated fiber optic components. Fiber optic cable and component manufacturers have been unable to establish a production base on which to project (predict) future prices. Users and potential users of fiber optic technology have only a minimal data base on which to build and expand their fiber optic applications.

Extensive research and development is required to establish both a high demand for quality fiber optic cable/components and the production base necessary to reduce the cost of fiber optic cable/components. As additional uses for fiber optic technology are discovered and fiber optic cable/component manufacturers strive to reduce manufacturing costs, available cost data will become more accurate.

The authors recommend a follow-on survey at such a time as both fiber optic users and producers have established a broader cost data base.

AIRCRAFT MANUFACTURERS

COST ELEMENT	DESCRIPTION	COST NUMBER	REMARKS
1.2.1.2	DESIGN ENGINEERING	0.80	Fewer cable location constraints with fiber optic cable. Note (2)
1.2.1.3	FABRICATION (TEST A/C)	0.95	Manufacturing costs using fiber optic cable will be only slightly less until a learning curve is established. Note (2)
1.2.1.4	DEVELOPMENT TESTS	$100,000	
1.2.1.5	TEST SUPPORT	$100,000	These COST NUMBERS are highly speculative and are sublect to extensive re-evaluation. Predicted values range from $50,000 to $250,000. Note (2)
1.2.1.8	TEST EQUIPMENT	$100,000	
2.1.4	TECHNICAL SUPPORT	1.00	Support costs for fiber optics will equal coax cost. Note (2)
2.1.6.3.2	MAINTENANCE TRAINING	$4,000 *	Assume 10 students/1 instructor/1 week course. Note (2)
2.1.10	TEST EQUIPMENT	1.30	Note (2)
3.1.1.	MANUFACTURING	0.85	After a learning curve is established, handling of fiber optic cable will be easier than coax. Note (3)
3.1.3	SUSTAINING ENGINEERING	0.80	Fewer cable location constraints with fiber optic cable. Note (4)
3.1.4	QUALITY CONTROL	1.00	Quality control costs of monitoring fiber optics will equal coax costs. Note (3)

Notes: (1) All COST NUMBERS are expressed in FY 76 dollars.
(2) A one time cost.
(3) An annual cost.
(4) Recurring cost as necessary.

* Denotes change from original data on 2-20-76

COST ELEMENT DATA SUMMARY

TABLE 1

COST ESTIMATING RELATIONSHIPS

COST ELEMENT	DESCRIPTION	COST NUMBER	REMARKS
2.1.5	INITIAL SPARES	2.45 *	Assume 10%plus 1 spare parts; a one time cost in FY 80 dollars, using 10% annual inflation and a 80% learning curve for fiber optics manufacturing
2.2.2.3.2	MAINTENANCE TRAINING	$8,000 *	Assume 10 students/1 instructor/1 week course. Calculated using DCA 600-60-1 publication.
2.2.2.3.3	INSTRUCTOR TRAINING	$8,000 *	Reduced the value calculated with DCA 600-60-1 by 50% due to the minimal level of effort anticipated for fiber optic training.
4.2.1.1.1	MAINTENANCE PERSONNEL	0.90	The predicted reliability of fiber optics will cause required maintenance to be reduced.
4.2.1.3	SUPPORT EQ. MAINTENANCE	1.00 *	Cost to maintain fiber optics support equipment will equal the cost for coax equipment.
4.2.2.3	SPARE PARTS	0.92 *	Assume 10% plus 1 spare parts; annual cost in FY 85 dollars, using 10% annual inflation and a 80% learning curve for fiber optics manufacturing
4.2.2.4.1	INVENTORY MANAGEMENT	1.60	Calculated using TRI-TAC publication.

* Denotes change from original data on 2-20-76

COST ELEMENT DATA SUMMARY

TABLE 1 (continued)

FIBER OPTICS MANUFACTURERS

COST ELEMENT	DESCRIPTION	COST NUMBER	REMARKS
3.1.2.1	PURCHASED PARTS	1.21 *	Annual cost is in FY 80 dollars, using 10% annual inflation and a 80% learning curve for fiber optics manufacturing

* Denotes change from original data on 2-20-76

NAVY SCHOOL COMMANDS

COST ELEMENT	DESCRIPTION	COST NUMBER	REMARKS
2.2.2.2	TRAINING DEVICES	2.00	One time cost to establish an inventory of fiber optics training devices, in FY 76 dollars.

COST ELEMENT DATA SUMMARY

TABLE 1 (continued)

APPENDIX J

Cost Element Identity

1.1.1

1.0 Research and Development
  1.1 Concept and Validation
    1.1.1 Contractor

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The cost of any Concept Initiation and Validation work that may be performed under the contract.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Application of a new technology would necessarily require concept studies and validation. The determining factor for total inclusion of this cost element was the extent and depth of present data available from either contractor efforts or Government research. (See also cost element 1.1.2) (Assumption 1).

1.0 Research and Development
1.1 Concept and Validation
1.1.2 Government

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The cost of any Concept Initiation and Validation work that may be performed by the Government.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Application of a new technology would necessarily require concept studies and validation. The work level addressed by this cost element would possibly be affected by the contractor work convered by cost element 1.1.1. However, the level of effort applied to either fiber optics or coax would be similar. (Assumption 1.)

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LIFE CYCLE COSTING OF AN EMERGING TECHNOLOGY: THE FIBER OPTICS --ETC(U)
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UNCLASSIFIED NPS-55JS76031 NL

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1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.1 Program management

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the technical and administrative planning, organizing, directing, coördinating, controlling, and approval actions designed to accomplish overall program objectives during the R&D phase of the equipment life cycle. Examples of these activities are configuration management, cost/schedule management, data management, contract management, liaison, value engineering, quality assurance and integrated logistic support management.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This element will be included in the total life cycle cost model only, because proper management of any program is essential. Depending upon the type of work, size of the contractor and the type of contract, this cost may just be included in the general category of overhead, regardless of the contractors effort, fiber optics or coax technology, this is a cost element applicable to both technologies.

1.0 Research and Development
1.2 Full Scale Development
1.2.1 Contractor
1.2.1.2 Engineering

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element refers to all engineering efforts associated with the system/equipment design and development. Specifically, this includes the cost of systems engineering and integration, design engineering (electrical, mechanical, drafting, etc.), design support (reliability, maintainability, human factors engineering and safety, value engineering, microelectronics), and the redesign or formulation of engineering changes. It includes the cost of direct labor, materials, overhead and other direct costs which must be incurred during the engineering process. The development of computer software is included herein as well as the cost of computer time. The engineering effort associated with peculiar support and test equipment is contained in 1.2.1.8.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Engineering during a Research and Development program is of primary importance to the final product. The development and application of a new technology is predominantly an engineering effort. It is anticipated that engineering costs

associated with fiber optic cable will be less than that engineering cost associated with copper cable. This is expected because of the predominately fewer restrictions placed on the allowable locations of fiber optic cables within an aircraft. This theory cannot be tested until a thorough Research and Development program has been executed.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.3 Fabrication

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the fabrication and assembly of full scale development models in support of the engineering design activity. Specifically, this includes the cost of direct labor, materials and overhead associated with material procurement and handling, tooling and test equipment in support of manufacturing, fabrication, assembly, system integration and checkout.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fabrication of prototype units is a prerequisite to effective test and evaluation. The integration of fiber optic cable into present copper cable signal carrying systems is dependent upon successful testing of prototype units. This effort would be required of both fiber optic and copper cable systems, and would therefore be a total life cycle cost element.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.4 Contractor Development Tests (CDT)

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

These tests are generally conducted on one or more prototype full scale development models at the contractor's facility to demonstrate that design specifications related to performance, control, maintenance, safety, maintainability, reliability, and human factors are satisfied. This cost element includes the cost of direct labor, materials, overhead and other direct charges required to perform CDT.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

In anticipation of reducing future fiber optic technology testing, specifically operational test and evaluation prior to final production, the fiber optic cable development tests will be extensive in scope.* This cost element coupled with cost element 1.2.1.5 will identify the associated costs. The Government will also actively participate in the Research and Development phase test. (See cost element 1.2.2.3.)

* The rationale is that once proven, fiber optic cable installation would not require any additional testing for RFI/EMI/NOISE immunity and other electrical cable problems.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.5 Test Support

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes those costs which are incurred in support of Government testing (DTE/IOTE). It may include the cost of site activation, consulting services, training, spare parts, maintenance, testing and/or the transportation of equipment and contractor testing personnel to the test site.

RATIONALE FOR INCLUSION/EXCLUSION IN MODEL

This cost element is required to include the contractor incurred costs associated with the Research and Development test program. (See cost elements 1.2.1.4 and 1.2.2.3.) The cost associated with fiber optic cable testing is expected to be a larger percentage of copper cable testing due to the extended scope of fiber optic testing conducted during the initial Research and Development test.

1.0 Research and Development
1.2 Full Scale Development
1.2.1 Contractor
1.2.1.1 Producibility Engineering and Planning (PEP)

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

PEP cosists of those planning and engineering tasks undertaken during the development phase to insure the timely and economic producibility of a component/item prior to release for production. PEP tasks consist of the following type activities: develop technical data packages, design special purpose production equipment and tooling, computer modeling/ simulation, engineering drawings, engineering, manufacturing and quality support information, dimensional and tolerance data, manufacture assembly sequences, wiring diagrams, material and finishing information, inspection, test and evaluation requirements, calibration information and quality control data.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is mandatory to insure a smooth transition from the Research and Development phase to production. This effort will be monitored by the Government through the Production Acceptance and Evaluation program. Regardless of the technology incorporated, fiber optics or coax, there is

a certain cost identified during the transition period from Research and Development to Production. (See cost element 2.2.3.)

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.7 Data
        1.2.1.7.1 Engineering Data

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The engineering data element refers to those engineering drawings, associated lists, specifications, and other documentation required by the Government. This element includes all plans, procedures, reports and documentation pertaining to systems, subsystems, component engineering, and testing.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required in order to obtain all necessary engineering data. Any engineering data that is developed after the Research and Development phase will be included in cost element 2.1.7.1. The cost of data collection and documentation would be independent of the technology being investigated.

1.2.1.7.2

1.0 Research and Development
1.2 Full Scale Development
1.2.1 Contractor
1.2.1.7 Data
1.2.1.7.2 Support Data

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The support data element refers to those data items required by the Government to develop and acquire the Support System. This included maintenance data, provisioning data and lists, support and test equipment data and lists, logistic support plans and progress reports, technical publications requirements data, training planning data and transportation and handling data, etc.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required in order to obtain all necessary support data. Any support data that is developed after the Research and Development phase will be included in cost element 2.1.7.2. The cost associated with data collection identified within this cost element would be similar for both fiber optic and coax technology.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.7 Data
        1.2.1.7.3 Management data

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The management data element refers to those data items necessary for configuration management, cost, schedule, contractual data mangement, programs management, etc., required by the Government.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required in order to obtain all necessary management data. Any management data that is developed after the Research and Development phase will be included in cost element 2.1.7.3. Fiber optic and coax technology would both have similar costs associated with them.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.7 Data
        1.2.1.7.4 Technical Orders and Manuals

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to those handbooks, technical manuals, technical orders, technical data sheets, etc. required by the Government.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required in order to obtain all necessary technical orders and manuals. Any system or equipment changes that occur after the Research and Development phase will be incorporated in technical orders and manuals covered under cost element 2.1.7.4. Even though fiber optics is a newer technology than coax, the costs associated with technical manuals would be the same.

1.0 Research and Development
1.2 Full Scale Development
1.2.1 Contractor
1.2.1.8 Peculiar Support and Test Equipment

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

Peculiar support equipment is that equipment, including tools, required to maintain and care for the system or portions of the system while not directly engage in the performance of its mission, and which have application peculiar to a given defense material item. It includes, for example, vehicles, equipment and tools used to service, transport and hoist, repair, overhaul, assemble, disassemble, test, inspect, or otherwise maintain the mission equipment. This cost element includes the cost of direct labor, materials, overhead and other direct charges required in the design development and test of the peculiar support equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic cable, once installed, will not require any special maintenance other than routine PMS checks. This does not eliminate the need for development of peculiar support and test equipment. There will be equipment developed that is compatible with the other fiber optic technology. (See cost elements 2.1.3.4 and 2.1.10.)

1.0 Research and Development
1.2 Full Scale Development
1.2.1 Contractor
1.2.1.9 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes all costs incurred by the contractor during full scale development not included in the previously listed elements.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The Research and Development costs associated with both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element. Neither technology in so complex nor filled with unknowns that additional Research and Development cost elements would be identified.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.1 Contractor
      1.2.1.10 General and Administrative (G&A)

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

G&A includes the expenses of a contractor's general and executive offices, the cost of staff services such as legal, accounting, public relations, financial, and similar expenses and other miscellaneous expenses related to the overall business. Included are directors' and executive committee members' fees, bonuses and incentive awards, employee stock portions, and employee fringe benefits.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

General and Administrative (G&A) costs are associated with every contractor. This is another portion of the contractors overhead expense but would be different for both fiber optic and coax research. Overhead is normally a fixed percentage of a contractors direct costs and a fiber optic Research and Development program would probably be more costly than a simular effort involving coax technology.

1.0 Research and Development
1.2 Full Scale Development
1.2.1 Contractor
1.2.1.11 Fee

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

Fee is that portion of the total contract price which is allowed a contractor over and above the cost to produce or perform.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

With the exception of a non-profit organization or educational institution, the contractor is expected to earn a fee. That fee would be the same regardless of the technology being researched. Since the fee earned would be quite similar for both technologies it would be improper to include it is the differential cost model. (Assumption 1.)

1.0 Research and Development
  1.2 Full Scale Development
    1.2.2 Government
      1.2.2.1 Program Management

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the technical and administrative planning, organizing, directing, coordinating, controlling, and approval actions designed to accomplish overall program objectives during the R&D phase of the equipment life cycle. Examples of these activities are configuration managment, cost/schedule management, data management, contract management, liaison, value engineering, quality assurance and integrated logistic support management.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Successful Government programs require a dedicated program management effort. This effort will be in addition to the contractor's program management includes as cost element 1.2.1.1. The Government cost to manage either a fiber optic or coax technology Research and Development program would be simular.

1.0 Research and Development
1.2 Full Scale Development
1.2.2 Government
1.2.2.2 Test Site Activation

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the costs incurred to prepare a test site for Government Testing. It includes the cost of transportation of equipment and testing personnel to the test site. The cost of direct labor, material, overhead and other direct charges is also included.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element must be included so that all Government costs associated with the Research and Development test program are identified. This cost element should be simular for both the fiber optic tests and for copper cable tests.

1.0 Research and Development
  1.2 Full Scale Development
    1.2.2 Government
      1.2.2.3 Government Tests (DTE/IOTE)

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

The Development Test and Evaluation (DTE) is designed to determine and/or verify technical performance and safety characteristics of an item, associated tools, and test equipment. It is conducted to: demonstrate that the engineering design and development process is complete; demonstrate that the design risks have been minimized; demonstrate that the system will meet specifications; and estimate the system's utility when introduced. Initial Operational Test and Evaluation (IOTE) is that portion of Operational Test and Evaluation performed during the FSD Phase prior to a production decision. The objectives are to provide information at the production decision point as to the system/equipment military use, expected operational effectiveness and operational suitability. This cost element includes the cost of direct labor, materials, overhead and other direct charges incurred in the conduct of DTE/IOTE. It also includes any Government costs in preparing test requirements, plans and procedures.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Test and Evaluation of fiber optic technology will be emphasized during the Research and Development phase. It is expected that thorough testing at this time will reduce or totally eliminate the need for operational test and evaluation prior to the final production phase. (See cost elements 1.2.1.4 and 1.2.1.5.)

1.0 Research and Development
  1.2 Full Scale Development
    1.2.2 Government
      1.2.2.4 Government Furnished Equipment (GFE)

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This is the effective cost to the Government of GFE supplied to the contractor during the full scale development phase of the equipment life cycle, Equipment loaned to a contractor and later returned to the Government in good condition may result in zero cost for this element if the cost of lost utility for the loaned equipment can be considered negligible.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The only anticipated Government Furnished Equipment will be included in cost element 2.2.2.2, training devices and equipment. A contractor would be expected to either develop or sub-contract for all necessary equipment.

1.0 Research and Development
1.2 Full Scale Development
1.2.2 Government
1.2.2.5 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes any cost incurred by the Government during full scale development which is not included in the previous elements.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The costs associated with both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element. Since the Governments involvement with the Research and Development would be predominately managerial, all cost elements would have been previously identified.

2.0 Investment (Non-Recurring)
  2.1 Contractor
    2.1.1 Program Management

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the technical and administrative planning, organizing, directing, coordinating, controlling, and approval actions designed to accomplish overall program objectives during the investment phase of the equipment life cycle. Examples of these activities are configuration management, cost/schedule management, data management, contract management, liaison, value engineering, quality assurance and integrated logistic support management.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Proper management is an essential ingredient in a successful program. This cost will normally be included as a portion of contractor overhead. A parallel management effort may be on-going within the Government. (See cost element 2.2.1.)

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.2 Producibility Engineering and Planning (PEP)

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

If PEP is not accounted for during the development phase (1.2.1.6) it shall be accounted for here. PEP consists of those planning and engineering tasks undertaken to insure the timely and economic producibility of a component/item prior to release for production. PEP tasks consist of the following type activities: develop technical data packages, design special purpose production equipment and tooling, computer modeling/simulation, engineering drawings, engineering, manufacturing and quality support information, dimensional and tolerance data, manufacture assembly sequences, wiring diagrams, material and finishing information, inspection, test and evaluation requirements, calibration information and quality control data.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Producibility Engineering and Planning (PEP) was identified and accounted for under the major category of Research and Development, cost element 1.2.1.6. The assumption was made that the Research and Development contractor would follow-on into the Production phase.

2.0 Investment (Non-Recurring)
  2.1 Contractor
    2.1.3 Initial Production Facilities
      2.1.3.1 Production Engineering

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This cost element includes that engineering necessary to translate the technical data package into a production line and also minor changes or fixes to the technical data package.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Production Engineering is the activity which helps insure a smooth transition from the development phase into final production. A required activity in order to finalize the programs production decision. Both fiber optic technology and coax technology would require a similar level of effort for the transition.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.3 Initial Production Facilities
2.1.3.2 Tooling

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes the costs incurred for the fabrication, assembly, installation, modification, and rework of all tools required for equipment assembly. It further includes the costs of dies, jigs, fixtures, gauges, handling equipment, and work platforms.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

It is anticipated that because of the physical simularities between fiber optic cable and copper cable there will be no special tooling required for installation or handling.

2.0 Investment (Non-Recurring)
  2.1 Contractor
    2.1.3 Initial Production Facilities
      2.1.3.3 Industrial Facilities

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

The industrial facilities element refers to the construction, conversion, or expansion of facilities for production. This includes real property acquisition or modernization where applicable. The cost of direct labor, material, overhead and other direct charges incurred in the actual set up of the final production line is also included here.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The installation of fiber optic cable in place of copper would not require a contractor to convert or expand his facilities. Those physical characteristics of fiber optic cable which would require production planning are similar to the physical characteristics of copper cable.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.3 Initial Production Facilities
2.1.3.4 Manufacturing Support Equipment

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

Manufacturing support equipment is that required in the manufacture and testing of the equipment being produced. Any special test devices, circuit checkout equipment, automatic machines, test assemblies, etc. are accounted for under this element. This element includes not only the cost of material, but the cost of the labor required to produce the support equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The present methods of checking for cable continuity will not be applicable to fiber optic cable. A new procedure will be required to send and receive a light signal in place of the conventional electrical signal continuity checks.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.4 Technical Support

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes the cost of any contractor technical support required by the Government during the investment phase of the equipment life cycle. An example would be contractor support during Government conducted Production Acceptance Test and Evaluation (PATE) and Operational Test and Evaluation (OTE).

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic cable does not possess the troublesome electrical properties inherent in copper cable, e.g., electro-magnetic interference (EMI), electrical ground problems, signal cross-talk. It is anticipated that no further testing will be required after testing is successfully completed during the Research and Development phase. (See cost element 1.2.1.4 and 1.2.1.5.)

2.0 Investment (Non-Recurring)
  2.1 Contractor
    2.1.5 Initial Spares and Repair Parts

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

The initial spares and repair parts element refers to the modules, spare components, and assemblies used for replacement purposes in major end items of equipment which are a part of the initial procurement. These initial spares and repair parts are separately costed, and are in addition to parts procured annually to replace initial spares or repair parts used for maintaining the equipment (4.2.2.3).

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

During the period of time the standard supply system is building its inventory of either fiber optic or copper cable components, initial spares will be required to support any new system. However, the fiber optic equipments or systems would require support peculiar to itself. Peculiar items would be fiber optic transmitting and receiving modules, connectors and the fiber optic cable itself.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.6 Initial Training
2.1.6.1 Training Facilities

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes the cost incurred in construction and general provisioning of special facilities for training. It accounts for only those facilities required by the system/ equipment under consideration.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The *similarities* between copper signal carriers and fiber optic cable preclude the necessity for special training facilities. Since Navy school facilities presently exist, any training unique to fiber optic technology would be directly incorporated into the existing facilities. (See cost element 2.2.2.1.)

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.6 Initial Training
2.1.6.2 Training Devices and Equipment

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This is the cost of any special training devices and equipment. This cost is a one time cost for the special equipment required in the training of operators and maintenance personnel. The cost of vugraphs, charts, test papers, and supplies is included under this element. Mission equipment used for training is covered as a recurring cost.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

It is anticipated that training devices required for initial operator and maintenance training will be furnished by the Government and included in cost element 2.2.2.2.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.6 Initial Training
2.1.6.3 Initial Student Training
2.1.6.3.1 Operator Training

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element represents the cost of training operators for the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

There will be no requirements for contractor supported operator training. Fiber optic cable used in place of copper cable will not cause any need to train operators. An operator is not primarily concerned with the method of signal transmission beyond that which can be learned through a short self study course. (See cost element 2.2.2.2.)

2.0 Investment (Non-Recurring)
 2.1 Contractor
  2.1.6 Initial Training
   2.1.6.3 Initial Student Training
    2.1.6.3.2 Maintenance Training

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element represents the cost of training maintenance personnel for the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Initial training of selected Navy maintenance personnel, both military and civilian, would be required to insure a smooth transition from contractor system or equipment support to full Navy support. The depth of training would be dependent upon the technology being taught. Fiber optic technology would require more instruction time than coax technology.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.6 Initial Training
2.1.6.3 Initial Student Training
2.1.6.3.3 Instructor Training

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element represents the cost of training instructor personnel.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The initial maintenance personnel training conducted by the contractor will utilize contractors' experienced personnel to augment the specially trained contractor instructors. (Assumption 3.)

2.0 Investment (Non-Recurring)
  2.1 Contractor
    2.1.7 Data
      2.1.7.1 Engineering Data

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The engineering data element refers to those engineering drawings, associated lists, specifications, and other documentation required by the Government. This element includes all plans, procedures, reports and documentation pertaining to systems, subsystems, and components engineering and testing.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required to obtain all engineering data not obtained during the Research and Development phase under cost element 1.2.1.7.1.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.7 Data
2.1.7.2 Support Data

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The support data element refers to those data items required by the Government to develop and acquire the Support System. This includes maintenance data, provisioning data and lists, support and test equipment data and lists, logistic support plans and progress reports, technical publications requirements data, training planning data and transportation and handling data, etc.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required to obtain all support data not obtained during the Research and Development phase under cost element 1.2.1.7.2.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.7 Data
2.1.7.3 Management Data

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The management data element refers to those data items necessary for configuration management, cost, schedule, contractual data management, programs management, etc., required by the Government.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required to obtain all management data not obtained during the Research and Development phase under cost element 1.2.1.7.3.

2.0 Investment (Non-Recurring)
 2.1 Contractor
  2.1.7 Data
   2.1.7.4 Technical Orders and Manuals

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to those handbooks, technical manuals, technical orders, technical data sheets, etc. required by the Government.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is required to obtain technical orders and manuals not obtained during the Research and Development phase under cost element 1.2.1.7.4.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.8 Leaseholds

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes the costs for leasing special or peculiar equipment, devices, communications circuits, or material to be used during the production of the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Since there is nothing unique or peculiar about the physical characteristics of fiber optic cable, there would be no requirements for special equipment during the production phase.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.9 Common Support Equipment

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

The common support equipment element refers to the equipment, including tools, required to maintain and care for the system or portions of the system while not directly engaged in the performance of its mission, and which are presently in the DoD inventroy for support of other systems. This element includes all effort required to assure availability of this equipment for support of the particular defense material item. It also includes the acquisition of additional quantities of these equipments if caused by the introduction of the defense material item into operational service.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic cable, once installed, will not require any special maintenance other than routine PMS checks. Contractor equipment required for routine checks was identified under cost element 2.1.10.

2.0 Investment (Non-Recurring)
  2.1 Contractor
    2.1.10 Peculiar Support and Test Equipment

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

Peculiar support equipment is that equipment, including tools, required to maintain and care for the system or portions of the system while not directly engaged in the performance of its mission, and which have application peculiar to a given defense material item. It includes, for example, vehicles, equipment, and tools used to service, transport and hoist, repair, overhaul, assemble, disassemble, test, inspect, or otherwise maintain the mission equipment. This cost element includes the cost of direct labor, materials, overhead and other direct charges required in the production of the peculiar support and test equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic cable, once installed, will not require any special maintenance other than routine PMS checks. The PMS checks and routine maintenance will require special equipment. This support equipment was developed under cost element 1.2.1.8.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.11 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes any contractor incurred non-recurring investment costs not contained in the previous cost elements.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The costs associated with both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.12 General and Administrative (G&A)

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

G&A includes the expenses of a contractor's general and executive offices, the cost of staff services such as legal, accounting, public relations, financial, and similar expenses and other miscellaneous expenses related to the overall business. Included are directors' and executive committee member's fees, bonuses and incentive awards, employee stock options, and employee fringe benefits.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

General and Administrative (G&A) costs are associated with every contractor. This is another portion of the contractor's overhead expense but would be different for both fiber optic and coax efforts since overhead is normally a fixed percentage of a contractor's direct costs. An anticipated savings in the use of fiber optic technology would be reflected in this cost element.

2.0 Investment (Non-Recurring)
2.1 Contractor
2.1.13 Fee or Profit

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

Fee is that portion of the total contract price which is allowed a contractor over and above the cost to produce or perform.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

With the exception of a non-profit organization or education institution, the contractor is expected to earn a fee or make a profit. That fee or profit would be the same regardless of the technology being researched. Since the fee earned would be quite similar for both technologies it would be improper to include it in the differential model. (Assumption 1.)

2.0 Investment (Non-Recurring)
2.2 Government
2.2.1 Program Management

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the technical and administrative planning, organizing, directing, coordinating, controlling, and approval actions designed to accomplish overall program objectives during the investment phase of the equipment life cycle. Examples of these activities are configuration management, cost/schedule management, data management, contract management, liaison, value engineering, quality assurance and itegrated logistic support management.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Successful Government programs require a dedicated program management effort. This effort will be in addition to the contractor's program management included in cost element 2.1.1.

2.0 Investment (Non-Recurring)
  2.2 Government
    2.2.2 Initial Training
      2.2.2.1 Training Facilities

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element incudes the cost incurred in construction and general provisioning of special facilities for training. It accounts for only those facilities required by the system/equipments under consideration.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

It is anticipated that all training required to introduce the fiber optic technology into the fleet would be conducted at presently existing Navy Training facilities. Any cost incurred to phase-in this fiber optic training will be included in cost elements 2.2.2.2 and 2.2.2.3.3. (See cost element 2.1.6.1.)

2.0 Investment (Non-Recurring)
2.2 Government
2.2.2 Initial Training
2.2.2.2 Training Devices and Equipment

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This is the cost of any special training devices and equipment. This cost is a one time cost for the special equipment required in the training of operators and maintenance personnel. The cost of vugraphs, charts, test papers, and supplies are included under this element. Mission equipment used for training is covered as a recurring cost.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element will include the cost of modifying present Navy class A/B/C school courses as applicable to include the new fiber optic technology. Development of a self-teaching guide to introduce fiber optics to operator personnel will be included here. (See cost element 2.1.6.3.1.)

2.0 Investment (Non-Recurring)
2.2 Government
2.2.2 Initial Training
2.2.2.3 Initial Student Training
2.2.2.3.1 Operator Training

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element represents the cost of training operators for the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The replacement of copper cable with fiber optic cable will not introduce a need for operator training. A basic overview of the use of fiber optics can be accomplished by the use of operator self-teaching guides developed under cost element 2.2.2.2.

2.0 Investment (Non-Recurring)
  2.2 Government
    2.2.2 Initial Training
      2.2.2.3 Initial Student Training
        2.2.2.3.2 Maintenance Training

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element represents the cost of training maintenance personnel for the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The contractor will be tasked to train an initial group of selected Navy maintenance personnel under cost element 2.1.6.3.2. The level of required training will vary for both fiber optic and coax technology. Fiber optic technology would be introduced as a new technology, while coax technology would build upon a Navy technicians' present knowledge of coax. (Assumption 3 and 4.)

2.0 Investment (Non-Recurring)
  2.2 Government
    2.2.2 Initial Training
      2.2.2.3 Initial Student Training
        2.2.2.3.3 Instructor Training

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element represents the cost of training instructor personnel.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

During the training by the contractor under cost element 2.1.6.3.2, a few select Navy school instructors will also attend the classes. This will allow the new fiber optic technology to be incorporated into existing formal Navy school training. The training of Navy instructors in fiber optic technology would require more time than a similar task associated with coax technology. (Assumption 4.)

2.0 Investment (Non-Recurring)
2.2 Government
2.2.3 Production Acceptance Test and Evaluation (PATE)

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

The production acceptance tests are conducted on production items produced early in the production run (generally identified as the "initial production run"). The tests are designed to insure that the production systems and equipment conform to design specifications and performance requirements when manufactured in accordance with production specifications and quantity production processes. This cost element includes the cost of direct labor, materials, overhead and other direct charges incurred in the conduct of PATE.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Production Acceptance Test and Evaluation (PATE) is required to insure a smooth transition from the Development phase to the Production phase. PATE is the Governments method of verifying the contractor's accuracy and completeness of his Producibility Engineering and Planning. This cost would be similar for either fiber optic or coax technology. (See cost element 1.2.1.6.)

2.0 Investment (Non-Recurring)
2.2 Government
2.2.4 Operational Test and Evaluation (OTE)

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

User Operational Tests and Evaluation (OTE) are tests generally conducted by user personnel (military unit(s)) under conditions of operational tactical environments. They are conducted to estimate the prospective system's military utility, operational effectiveness, and operational suitability (including compatibility, interoperability, reliability, maintainability, and logistic and training requirements), and need for any modifications. In addition, OTE provides information on organization, personnel requirements, doctrine, and tactics. Also it may provide data to support or verify material in operating instructions, publications, and handbooks. This element includes the cost of labor, material, overhead and other direct charges incurred in the conduct of OTE.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Replacement of copper cable with fiber optic cable will not require additional operational test and evaluation beyond the testing accomplished during the Research and Development (R&D) phase. Testing accomplished during R&D will be the

determining factor when considering fiber optics for production use. Without sufficiently good results from the Research and Development tests, fiber optic technology would not be considered for production. (See cost element 1.2.2.3.)

2.0 Investment (Non-Recurring)
2.2 Government
2.2.5 Test Site Activation

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element refers to the costs required to prepare test sites for OTE. This includes construction, conversion, expansion, modification, modernization and installation as required. The costs of direct labor, material, overhead and other direct charges are included.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The lack of a requirement for operational test and evaluation after the Research and Development phase (see cost element 2.2.4) precludes the need for a test site.

2.0 Investment (Non-Recurring)
2.2 Government
2.2.6 Government Furnished Equipment (GFE)

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This is the effective cost to the Government of GFE supplied to the contractor during the investment phase of the equipment life cycle. Equipment loaned to a contractor and later returned to the Government in good condition may result in zero cost for this element if the cost of lost utility for the loaned equipment can be considered negligible.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The only anticipated Government Furnished Equipment will be included in cost element 2.2.2.2, training devices and equipment.

2.0 Investment (Non-Recurring)
2.2 Government
2.2.7 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes any Government incurred non-recurring investment cost not contained in the previous cost elements.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The costs associated with both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element. There should be no areas of cost not previously identified as a cost element.

3.0 Investment (Recurring)
3.1 Contractor
3.1.1 Manufacturing

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

Manufacturing includes the direct labor, overhead and other direct charges incurred during the fabrication, processing, subassembly, final assembly, reworking, modification and installation of parts and equipment to an end item of equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost elements includes a large portion of the fiber optic or coax equipment costs. In addition to the costs identified in this cost element, the costs associated with elements 3.1.2.1, 3.1.2.2 and 3.1.2.3 *form* another large portion of the equipment cost.

3.0 Investment (Recurring)
3.1 Contractor
3.1.2 Production Material
3.1.2.1 Purchased Equipment and Parts

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes the cost of manufactured and assembled items, usually procured from outside sources by the contractor. Purchased equipment usually costs in excess of $100 per unit and exhibits a wide range of complexity. It is usually termed off-the-shelf equipment and consists of, for example, batteries, motors, generators, air conditioning equipment, hydraulic pumps and instruments. Purchased parts are distinguished from purchased equipment by cost and complexity. Usually purchased parts cost under $100 per unit and are essentially standard, off-the-shelf hardware items.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is included in order to identify all off-the-shelf items which are consumed in the production of the prime equipments or systems.

3.0 Investment (Recurring)
3.1 Contractor
3.1.2 Production Material
3.1.2.2 Subcontractor Items

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes the cost of parts, components and assemblies produced by manufacturers other than the prime contractor in accordance with the prime contractor's designs, specifications or directions. It does not include equipment bought off-the-shelf. It does include the cost of transportation or shipment if itemized by the subcontractor.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is included in order to identify all subcontractor produced items which are consumed in the production of the prime equipments or systems.

3.0 Investment (Recurring)
  3.1 Contractor
    3.1.2 Production Material
      3.1.2.3 Other Material

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes all the raw and semifabricated material, intercompany transfers and other material used in the production of the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is included in order to identify all other materials produced or purchased for consumption in the production of the prime equipments or systems. Nearly all costs would have been identified and associated with a particular cost element. However, to ensure completeness this cost element is included.

3.0 Investment (Recurring)
3.1. Contractor
3.1.3 Sustaining Engineering

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

All Engineering performed after quantity production starts is included in this element. This will include such items as maintainability-reliability engineering, maintnenace engineering, value engineering, and production engineering. It also includes redesign, evaluation, and other sustaining efforts of the engineering function.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Unless specifically rejected by a contractual agreement, sustaining engineering will be included as a portion the equipment or system life cycle cost. This is applicable to both fiber optic and copper cable systems. However, the anticipated benefits gained through the use of fiber optic cable in lieu of coax will probably reduce the cost of activities such as air craft modifications or field changes.

3.0 Investment (recurring)
3.1 Contractor
3.1.4 Quality Control and Inspection

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This includes such tasks as receiving inspection, in-process and final inspection of tools, parts, subassemblies and complete assemblies. Quality Control is that function of management relative to all procedures, inspections, examinations, and tests requied during procurement, production, receipt, storage, and issue that are necessary to provide the user with an item of the required quality.

RATIONAL FOR INCLUSION/EXCLUSION IN COST MODEL

Quality control is an ever-continuing requirement to maximize the system or equipment quality. There would be little difference between fiber optic and coax technology quality control. The Government monitors this quality control and inspection effort continually. (See cost element 3.2.1.)

3.0 Investment (Recurring)
3.1 Contractor
3.1.5 Packaging and Transportation

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This includes the costs associated with packing the article for shipment and transportation from the point of procurement production or testing to the first destination under contract.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is included as a regular input to the total life cycle cost. At a minimum, the contractor will be required to provide packaging for equipment spare parts prior to shipment to the Navy for inclusion into the supply system.

3.0 Investment (Recurring)
3.1 Contractor
3.1.6 Operational/Site Activation
3.1.6.1 Site Construction

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

The site construction element refers to the real estate, site preparations, construction, and other special-purpose facilities necessary to achieve system operational status. This element also includes the construction of utilities, roads, and interconnecting cabling.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The use of fiber optic cable in lieu of copper cable will not generate a requirement for special-purpose facilities construction. Use of fiber optic technology would require working conditions very similar to those required by the use of coax technology.

3.0 Investment (Recurring)
3.1 Contractor
3.1.6 Operational/Site Activation
3.1.6.2 Site/Ship/Vehicle Conversion

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

The site/ship/vehicle conversion element refers to all materials and services required to provide for the conversion/modification of existing site/ship/vehicle to accomodate the mission equipment and selected support equipment directly related to the specific system.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

If fiber optic cable is to be used in place of existing copper cable then there will be a conversion cost identified. Since the applications of fiber optic technology are few in number, any use of fiber optics, in the near future, would generate some level of conversion requirement and associated cost. Conversion to coax technology would have a cost associated with it but the fewer installation restrictions placed on fiber optic cable would make the conversion to fiber optic technology less costly.

3.0 Investment (Recurring)
3.1 Contractor
3.1.6 Operational/Site Activation
3.1.6.3 Assembly, Installation and Checkout

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element refers to the materials and services involved in the assembly of mission and support equipment at the site. It includes the complete system checkout or shakedown to insure achievement of operational status.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

In conjunction with cost element 3.1.6.2, the contractor will be required to verify the system or equipment after his conversion work. It is anticipated that the fewer restrictions associated with fiber optic technology would make the cost less than a similar effort using coax technology.

3.0 Investment (Recurring)
3.1 Contractor
3.1.7 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This cost element includes any contractor incurred recurring investment costs not contained in the previous cost elements.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The costs associated with both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element.

3.0 Investment (Recurring)
3.1 Contractor
3.1.8 General and Administrative (G&A)

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

G&A includes the expenses of a contractor's general and executive offices, the cost of staff services such as legal, accounting, public relations, financial, and similar expenses and other miscellaneous expenses related to the overall business. Included are chairman's and executive committee members' fees, bonuses and incentive awards, employee stock options, and employee fringe benefits.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

General and Administrative (G&A) costs are associated with every contractor. This is another portion of the contractor's overhead expense but would be different for both fiber optic and coax efforts since overhead is normally a fixed percentage of his direct costs. It is assumed that the direct costs of a task requiring fiber optic technology would be less than similar costs for coax technology.

3.0 Investment (Recurring)
3.1 Contractor
3.1.9 Fee or Profit

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

Fee is that portion of the total contract price which is allowed a contractor over and above the cost to produce or perform.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

With the exception of a non-profit organization or educational institution, the contractor is expected to earn a fee or make a profit. That fee or profit would be the same regardless of the technology being researched. Since the fee earned would be similar for both technologies it would be improper to include it in the differential model. (Assumption 1.)

3.0 Investment (Recurring)
3.2 Government
3.2.1 Quality Control and Inspection

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes all Government quality control and inspection activities at the contractor's plant or at first destination.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The Government has an on-going program to monitor the contractor's quality control program (see Cost Element 3.1.4). This quality control is incorporated into all major contractual agreements and would be similar in scope for either fiber optic or coax technology.

3.0 Investment (Recurring)
3.2 Government
3.2.2 Sustaining Engineering

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

All Government engineering performed after quantity production starts is included in this element. This will include such items as maintainability-reliability engineering, maintenance engineering, value engineering, and production engineering. It also includes the preparation, at depot level, for assuming the engineering function during the operating and support phase of the equipment life cycle.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The contractor is tasked under cost element 3.1.3 to perform sustaining engineering. The Government will follow the contractors efforts and be the recipient of the data obtained.

3.0 Investment (Recurring)
3.2 Government
3.2.3 Transportation

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes all transportation, storage and handling costs of the prime mission equipment from the point of procurement, production or testing to the user.

RATIONAL FOR INCLUSION/EXCLUSION IN COST MODEL

The contractor will provide handling and transportation to a predetermined position. If additional packing, transportation and storage is required than the Government will fund the additional cost through cost element 3.1.5.

3.0 Investment (Recurring)
3.2 Government
3.2.4 Operational/Site Activation
3.2.4.1 Site Construction

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

The site construction element refers to the real estate, site preparation, construction, and other special-purpose facilities necessary to achieve system operational status. This element also includes the construction of utilities, road, and interconnecting cabling.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The use of fiber optic cable in lieu of copper cable will not gererate a requirement for special-purpose facilities construction.

3.0 Investment (Recurring)
3.2 Government
3.2.4 Operational/Site Activation
3.2.4.2 Site/Ship/Vehicle Conversion

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

The site/ship/vehicle conversion element refers to all materials and services required to provide for the conversion/ modification of existing site/ship/vehicle to accomodate the mission equipment and selected support equipment directly related to the specific system.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Any conversion work will be a contractor effort and there will be no direct Government involvement. Government involvement would be in the form of management. (See cost element 3.1.6.2.)

3.0 Investment (Recurring)
3.2 Government
3.2.4 Operational/Site Activation
3.2.4.3 Assembly, installation and Checkout

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This cost element refers to the materials and services involved in the assembly of mission and support equipment at the site. It includes complete system checkout or shakedown to insure achievement of operational status.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Since the Government will not be directly involved in conversion work, there will be no cause for direct involvement in system or equipment checkouts. (See cost element 3.1.6.3.)

3.0 Investment (Recurring)
3.2 Government
3.2.5 Technical Orders and Manuals

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element covers the cost of assembling and publishing technical manuals/orders and other documents shipped with the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost will be required to finalize the technical orders and manuals received from the contractor during both the Research and Development phase and the Production phase under cost elements 1.2.1.7.4 and 2.1.7.4. There would be no difference in the cost of assembling and publishing either fiber optic or coax technology manuals.

3.0 Investment (Recurring)
3.2 Government
3.2.6 Government Furnished Material

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes the cost for any materials provided to a contractor for incorporation in the end article being procured. An example of such material misht be microcircuit chips for COMSEC equipment.

RATIONAL FOR INCLUSION/EXCLUSION IN COST MODEL

The only anticipated Government Furnished Material will be included in cost element 2.2.2.2, training devices and equipment.

3.0 Investment (Recurring)
3.2 Government
3.2.7 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This includes any Government recurring investment costs not included in the elements listed previously.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The costs associated both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element. No costs other than those already identified can be anticipated at this time.

4.0 Operating and Support
4.1 Operations
4.1.1 Electrical Power

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

The cost of electrical power is the cost of battery, generator, or commercially supplied power required for the operation of the equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost is not applicable since power will be supplied to the equipments which will be interconnected by the fiber optic cables. There are no electrical power requirements for the fiber optic cable. Initial equipment or system design would account for any reduction in actual operating power requirements.

4.0 Operating and Support
4.1 Operations
4.1.2 Special Materials

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element covers the cost of materials consumed in the operation of the equipment. Examples of some typical items and materials are POL (petroleum, oil and lubricants), facsimile paper and paper rolls and paper tapes used with teletypewriter equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic cables require no consumable material during their normal life time. This cost element is not included in the cost model since the only "consumable" materials are maintenance spare parts. Spare parts are included in cost element 4.2.2.3

4.0 Operating and Support
4.1 Operations
4.1.3 Operator Personnel

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This cost element is the manpower cost, direct and indirect, this is incurred in operating the equipment. Included within the determination of manpower cost is not only the cost of the operator's pay and allowances, but also the miscellaneous expenses, support costs, incentive and special pay, and replacement training costs.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic cable requires no direct operator procedures. It is only a signal carrying medium between equipments and is totally a passive device.

4.0 Operating and Support
4.1 Operations
4.1.4 Operational Facilities

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element refers to the annual maintenance of facilities used to house prime mission equipment. This includes maintenance of real property where applicable. All direct labor, material, overhead and other direct charges are included.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The fiber optic cables become an integral part of the structure which encloses and supports the basic equipment being interconnected. There can be no maintenance cost attributable to the fiber optic cable installed within.

4.0 Operating and Support
4.1 Operations
4.1.5 Equipment Leaseholds

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes costs for leasing special or peculiar equipment, devices, communication circuits, or material during the operating life cycle phase of the equipment/ system.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Since there is nothing unique or peculiar about the physical characteristics of fiber optic or coax cable, there would be no requirement for special equipment during the operating phase of equipments or systems.

4.0 Operating and Support
4.1 Operations
4.1.6 Other

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes other operations costs not included previously. The following are examples of these possible costs:

- Operating Costs related to equipment shelters (i.e., heating and air conditioning);
- The cost of transportation of special material from Central Supply locations/depots to the user if not included in the cost of the special material;
- Transportation costs of the prime mission equipment for purpose of operation (i.e., training exercises, deployments, etc.). For mobile tactical equipment, this basically involves POL for transporting vehicles.
- Opportunity cost of a non-available (down) aircraft due to electrical cable problems.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fibers optic technology is expected to increase equipment or system reliability. Therefore a constant cost per day (C) can be established as the opportunity cost of a down aircraft. This is the cost of not having the aircraft due to wiring problems and must be evaluated as both a total cost and a differential cost to determine the cost of unreliability.

4.0 Operating and Support
4.2 Logistic Support
4.2.1 Maintenance
4.2.1.1 Personnel
4.2.1.1.1 Organizational Maintenance Personnel

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This element includes that portion of the maintenance personnel costs associated with the organizational level of maintenance to include corrective and preventive maintenance. Organizational maintenance is that maintenance which is the responsibility of and performed by a using organization on its assigned equipment. Its phases normally consist of inspecting, servicing, lubricating, adjusting, and the replacement of parts, minor assemblies and sub-assemblies.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is included because it includes the routine PMS performed on the equipment or system and the system or equipment corrective maintenance. Maintenance must be performed regardless of whether the aircraft has fiber optic cable, copper cable or both, but it is anticipated that fewer maintenance actions would be required on fiber optic cable. (Assumption 6.)

4.0 Operating and Support
4.2 Logistic Support
4.2.1 Maintenance
4.2.1.1 Personnel
4.2.1.1.2 Intermediate Maintenance Personnel

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes that portion of maintenance personnel costs associated with the intermediate level of maintenance. Intermediate maintenance is that maintenance which is the responsibility of and performed by designated maintenance activities for support of using organizations. Its phases normally consist of calibration, repair or replacement of damaged or unserviceable parts, components or assemblies; the manufacture of critical non-available parts; and providing technical assistance to using organizations. Intermediate maintenance is normally accomplished in fixed or mobile shops, tenders, or shore based repair facilities, or by mobile teams.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic technology will proceed to the degree of module replacement. This type maintenance will be performed by organizational level personnel and intermediate level personnel will not be required. The requirement for intermdediate level maintenance personnel would exist for major rework due to aircraft modification or on an as required basis only. (Assumption 5.)

4.0 Operating and Support
4.2 Logistic Support
4.2.1 Maintenance
4.2.1.1 Personnel
4.2.1.1.3 Depot Maintenance Personnel

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes that portion of maintenance personnel costs associated with the depot level of maintenance. To simplify life cycle cost calculations, this element also includes the cost of material, depot overhead and other direct charges required to overhaul or repair the equipment. Depot maintenance is that maintenance which is the responsibility of and performed by designated maintenance activities, to augment stocks of serviceable material, and to support Organizational maintenance and Intermediate maintenance activities by the use of more extensive shop facilities, equipment and personnel of higher technical skill than are available at the lower levels of maintenance. Its phases normally consist of inspection, test, repair, modification, alteration, modernization, conversion, overhaul, reclamation, or rebuild of parts, assemblies, sub-assemblies, components, equipment and items, and weapon systems; the manufacture of critical non-available parts; and providing technical assistance to intermediate maintenance organizations, using and other activities. Depot maintenance is normally accomplished

in fixed shops, shipyards and other shore based facilites, or by depot field teams.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The state-of-the-act advancements will cause the modular replacement concept to proceed to throw away modules. Depot maintenance will not be required to service fiber optic components, but could be called upon to assist intermediate maintenance personnel for extensive corrective maintenance. (Assumption 5.)

4.0 Operating and Support
4.2 Logistic Support
4.2.1 Maintenance
4.2.1.2 Maintenance Facilities

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the annual upkeep of facilities for maintenance. This includes upkeep of real property where applicable. All direct labor, material overhead and other direct charges are included.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Maintenance facilities at the organizational level exist presently and the replacement of copper cable with fiber optic cable would cause no cost changes. Intermediate and depot level facilities would be selectively required and therefore there could be a cost associated with them. (See cost elements 4.2.1.1.2 and 4.2.1.1.3.)

4.0 Operating and Support
4.2 Logistic Support
4.2.1 Maintenance
4.2.1.3 Support Equipment Maintenance

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This cost element includes the cost of maintenance and calibration of the common and peculiar support equipment.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element must be included in order to include the maintenance and calibration of support equipment peculiar to the fiber optic technology. There already exists equipment capable of support of coax technology.

4.0 Operating and Support
4.2 Logistic Support
4.2.1 Maintenance
4.2.1.4 Contractor Services

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes contractor costs for engineering and technical services and maintenance of the system/equipment. Contractor engineering and technical services include those services provided by commercial or industrial companies for advice, instruction and training to DoD personnel in the installation, operation and maintenance of the equipment/system. Contract maintenance includes the cost incurred for maintenance of the equipment by commercial organizations on a one-time or continuing basis, without distinction as to the level of maintenance accomplished. All direct labor, material, overhead and other direct charges are included.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

Fiber optic technology is expected to advance the state-of-the-art to the point where all maintenance will be performed by organizational level maintenance personnel. Historical data indicated that contractor services required in the present electrical systems have been minimal. (See cost element 4.2.1.1.1.)

4.0 Operating and Support
4.2 Logistic Support
4.2.2 Supply
4.2.2.1 Personnel
4.2.2.1.1 Organizational Supply Personnel

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes that portion of the supply personnel costs associated with the organizational level of supply. Material control personnel under the control of the Maintenance Department are included herein.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

These organizational supply personnel must be included in order to accumulate the total life cycle cost, even though the differential cost between copper cable and fiber optic is negligible. Actual organizational supply processing of either fiber ptic or coax components would be quite similar.

4.0 Operating and Support
  4.2 Logistic Support
    4.2.2 Supply
      4.2.2.1 Personnel
        4.2.2.1.2 Intermediate Supply Personnel

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes that portion of supply personnel costs associated with the intermediate level of supply. Base Supply personnel on a military Base are included herein.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

These supply organization personnel must be included in order to accumulate the total life cycle cost, even though the differential cost between copper cable and fiber optic cable is negligible.

4.0 Operating and Support
  4.2 Logistic Support
    4.2.2 Supply
      4.2.2.1 Personnel
        4.2.2.1.3 Depot Supply Personnel

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element includes that portion of the supply personnel costs associated with the depot level of supply if not included in 4.2.2.4.2.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

These supply organization personnel must be included in order to accumulate the total life cycle cost, even though the differential cost between copper cable and fiber optic cable is negligible.

4.0 Operating and Support
4.2 Logistic Support
4.2.2 Supply
4.2.2.2 Supply Facilities

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This element refers to the maintenance of facilities for supply. It includes maintenance of real property where applicable. All direct labor, material, overhead and other direct charges are included. General storage costs are included in Inventory Holding Costs (4.2.2.4.2).

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The supply facilities maintenance must be included in order to accumulate the total life cycle cost, even though the differential cost between copper cable and fiber optic cable is negligible.

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4.0 Operating and Support
  4.2 Logistic Support
    4.2.2 Supply
      4.2.2.3 Spare Parts and Repair Material

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This cost element represents the cost of the repair parts, assemblies, consumables and other materials consumed in the maintenance process. Initial spares and repair parts purchased during the production are considered an expended cost, and therefore are not included in this cost element. Material required during depot overhaul is covered in Depot Maintenance Personnel (4.2.1.1.3).

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element is considered a routine element in a cost model. Neither fiber optics nor coax require consumable parts support, but both technologies require replacement parts. The reliability of fiber optic technology is expected to be greater than that of coax. Therefore the fiber optic repair part cost should be less than coax parts cost.

4.0 Operating and Support
4.2 Logistic Support
4.2.2 Supply
4.2.2.4 Inventory Administration
4.2.2.4.1 Inventory Management

(X) Total
(X) Differential
( ) Excluded

DESCRIPTION

This cost element refers to the management costs for entering and maintaining an item in inventory. The costs include identification, description, sumission to and screening and editing by Data Documents Center, inclusion in maintenance and supply catalogs, establishing by supply management of inventory and replacement rates, provisioning, requisitioning, rebuild directions, and procurement directives.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element must be included in order to accumulate the total life cycle cost. The differential costs between copper technology and fiber optic technology are expected to be the transmitting and receiving modules, connectors and the fiber optic cable itself. Many coax technology components exist within the supply system at this time.

4.0 Operating and Support
4.2 Logistic Support
4.2.2 Supply
4.2.2.4 Inventory Administration
4.2.2.4.2 Inventory Holding

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

Inventory holding is the cost of physically holding inventory in the supply system for one year. The factors included are: general storage cost, deterioration in storage, obsolescence, and losses in storage.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This supply cost element must be included in order to accumulate the total life cycle cost, even though the differential cost between copper cable and fiber optic cable is negligible.

4.0 Operating and Support
4.2 Logistic Support
4.2.2 Supply
4.2.2.5 Transportation and Packaging

(X) Total
( ) Differential
( ) Excluded

DESCRIPTION

This cost element includes packaging, handling and transportation of spares, repair parts and other material between organizational, intermediate, depot and supply points (overseas and CONUS) in support of maintenance operations. Also included is the transportation of the end item to the depot and return for the purpose of depot overhaul.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

This cost element must be included in order to accumulate the total life cycle cost, even though the differential cost between copper cable and fiber optic cable is negligible.

4.0 Operating and Supply
4.2 Logistic Support
4.2.3 Other

( ) Total
( ) Differential
(X) Excluded

DESCRIPTION

This element includes any logistic support costs not specifically included in the previously listed elements. Maintenance and logistic support of shelters, vehicles, ECU's, power generators and other ancillary equipment may be included herein as appropriate.

RATIONALE FOR INCLUSION/EXCLUSION IN COST MODEL

The costs associated with both fiber optic and copper cable technology should be quantifiable and directly assessable to a specific cost element.

APPENDIX K

Data Source Guide

1.2.1.2

ENGINEERING

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for this cost data would be aircraft manufacturers experienced in aircraft electrical signal interconnect design.

Delphi Questionnaire sections I, II and III are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question III-1 will produce the required cost data.

CONTRACTOR DEVELOPMENT TESTS

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for the cost data would be aircraft manufacturers experienced in development test procedures.

Delphi Questionnaire sections I, II and III are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question III-2 will produce the required cost data.

TEST SUPPORT

Assuming that the fiber optic performance characteristics successfully pass the Research and Development contractor development tests, it is anticipated that the Government will conduct an extensive Development Test and Evaluation program as a final assurance of operational quality.

Collection of cost data for the cost element will be a two step process. The analyst must first determine the magnitude of testing to be conducted under cost element 1.2.2.3. Secondly the information received as a response to the Delphi Questionnaire must be combined with that information to determine the final cost data.

Delphi Questionnaire sections I, II and III are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question III-3 will produce the required cost data.

PECULIAR SUPPORT AND TEST EQUIPMENT

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for this cost data will be aircraft manufacturers experienced in the development of aircraft support equipment.

Delphi Questionnaire sections I, II and III are applicable to the cost element and would be forwarded to the aircraft manufactuers. Question III-4 will produce the required cost data.

GENERAL AND ADMINISTRATIVE

This is a Category II cost element for which cost data can be collected from an aircraft manufacturer's historical files. The required information could be obtained without the use of a Delphi Questionnaire but this question was included in order to consolidate all data.

Delphi Questionnaire sections I, II and III are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question III-5 will produce the required cost data.

GOVERNMENT TESTS (DTE/IOTE)

This is a unique cost element in that there is no industry counterpart to a Government testing agency. To obtain cost data for this element, the analyst will be required to search files on previously conducted tests and contact the known Government testing agencies.

A recommended data source is the office of the Operational Test and Evaluation Forces (OPTEVFOR).

MANUFACTURING SUPPORT EQUIPMENT

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for this cost data would be aircraft manufacturers experienced in establishing production equipment requirements.

Delphi Questionnaire sections I, II and IV are applicable to this cost element and would be forwarded to the aircraft manufacturer. Question IV-1 will produce the required cost data.

TECHNICAL SUPPORT

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The cost data predicted for this cost element is subject to a wide variance due to its subjective nature. The source for the cost data would be aircraft manufacturers familiar with the technical support requirements of Government Test Programs.

Delphi Questionnaire sections I, II and IV are applicable to this cost element and would be forwarded to the aircraft manufacturer. Question IV-2 will produce the required cost data.

INITIAL SPARES AND REPAIR PARTS

These spare and repair parts are a one-time procurement and the quantity is dependent upon the output of a level of repair (LOR) analysis. Cost data for individual components can be obtained directly from the fiber optic component manufacturers or the purchase records of an aircraft manufacturer.

COST FORMULA

$$\begin{bmatrix}\text{Initial Spares}\\ \text{and}\\ \text{Repair Parts}\end{bmatrix} = \sum_{i=1}^{N} \begin{bmatrix}\text{Quantity}\\ \text{of Repair}\\ \text{Part } i\end{bmatrix} \times \begin{bmatrix}\text{Price}\\ \text{of Repair}\\ \text{Part } i\end{bmatrix}$$

COST FACTORS	UNITS
QUANTITY OF REPAIR PART i	EA.
PRICE OF REPAIR PART i	$/EA.

COMMENT

N is the total number of unique spare parts procured

i identifies each unique spare part.

MAINTENANCE TRAINING

An experienced aircraft manufacturer will have a historical file of costs associated with previous training programs that were conducted by the firm. Since the establishment of a training program is a routine procedure, the available historical cost can be a data base used to extrapolate new cost data.

Delphi Questionnaire sections I, II and IV are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question IV-3 will produce the required cost data.

PECULIAR SUPPORT AND TEST EQUIPMENT

This is a Category I cost element which will use the Delphi Questionnaire Technique to obtain cost data. The source for this cost data would be aircraft manufacturers experienced in the development and production of aircraft support equipment.

Delphi Questionnaire sections I, II and IV are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question IV-4 will produce the required cost data.

GENERAL AND ADMINISTRATIVE

This is a Category II cost element for which cost data can be collected directly from an aircraft manufacturer historical files. The required information could be obtained without the use of a Delphi Questionnaire but this question was included in order to consolidate all data.

Delphi Questionnaire sections I, II and IV are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question IV-5 will produce the required cost data.

TRAINING DEVICES AND EQUIPMENT

The costs associated with the development of existing training devices and equipment and their implementation into Navy schools are available through the office of CNET. There are no major training device requirements anticipated, therefore this effort should be within the present state-of-the-art.

The Delphi Questionnaire would serve no purpose where obtaining cost data for this element. Direct contact with the appropriate CNET offices would be the most effective method of data collection.

MAINTENANCE TRAINING

The economic cost of military personnel includes the following cost elements:

(1) basic pay and allowances

(2) PCS travel

(3) Retirement

(4) Support costs

(5) Replacement training

Referring to the tables in reference 33 the annual cost of training a maintenance man in a new technology is:

COST FORMULA

$$\begin{bmatrix}\text{Maintenance}\\\text{Training}\\\text{Cost}\end{bmatrix} = \begin{bmatrix}\text{Basic Pay}\\\text{and}\\\text{Allowance}\end{bmatrix} + \begin{bmatrix}\text{PCS}\\\text{Travel}\end{bmatrix} + \begin{bmatrix}\text{Retire-}\\\text{ment}\end{bmatrix} + \begin{bmatrix}\text{Support}\\\text{Costs}\end{bmatrix} + \begin{bmatrix}\text{Replacement}\\\text{Training}\end{bmatrix}$$

COST FACTORS	UNITS
Basic Pay and Allowances	$/yr.
PCS Travel	$/yr.
Retirement	$/yr.
Support Costs	$/yr.
Replacement Training*	$/yr.

* DCA Circular 600-60-1 can be used where no specific training course yet exists.

To determine the daily training cost

divide $\begin{bmatrix} \text{Maintenance} \\ \text{Training} \\ \text{Cost} \end{bmatrix}$ by the number of anticipated

work days per year.

INSTRUCTOR TRAINING

The assumption was previously made that Navy instructors would be trained during the same time period as maintenance personnel. Therefore the same cost relationship as used to calculate costs for maintenance training (cost element 2.2.2.3.2) can be used for this element.

Referrring to the tables in reference 33 the annual cost of training an instructor in a new technology is:

COST FORMULA

$$\begin{bmatrix}\text{Instructor}\\\text{Training}\\\text{Cost}\end{bmatrix} = \begin{bmatrix}\text{Basic Pay}\\\text{and}\\\text{Allowance}\end{bmatrix} + \begin{bmatrix}\text{PCS}\\\text{Trav-}\\\text{el}\end{bmatrix} + \begin{bmatrix}\text{Retire-}\\\text{ment}\end{bmatrix} + \begin{bmatrix}\text{Support}\\\text{Costs}\end{bmatrix} + \begin{bmatrix}\text{Replace-}\\\text{ment}\\\text{Training}\end{bmatrix}$$

COST FACTORS	UNITS
Basic Pay and Allowances	$/yr.
PCS Travel	$/yr.
Retirement	$/yr.
Support Costs	$/yr.
Replacement Training*	$/yr.

* DCA Circular 600-60-1 can be used where no specific training course yet exists.

To determine the daily training cost

divide $\begin{bmatrix}\text{Instructor}\\\text{Training}\\\text{Cost}\end{bmatrix}$ by the number of anticipated work days per year.

MANUFACTURING

This is a Category I cost element which will use the Delphi Questionnaire Technique to obtain cost data. The sources for the cost data would be aircraft manufacturers experienced in aircraft production.

Delphi Questionnaire sections I, II and V are applicable to this cost element and would be forwarded to the aircraft manufacturer. Question V-1 will produce the required cost data.

PURCHASED EQUIPMENT AND PARTS

A somewhat different approach must be taken to gather data for this cost element and cost elements 3.1.2.2 and 3.1.2.3. The analyst must obtain a list of the fiber optic component requirements for a specific task from a aircraft manufacturer. This fiber optic component list can then be priced with, the use of the cost data received from the fiber optic industry via the Delphi Questionnaire in Appendix L or actual catalog prices.

The Delphi Questionnaire in Appendix L would be forwarded to the fiber optic manufacturer/R&D activities found in the NELC composite distribution list.

SUBCONTRACTED ITEMS

A somewhat different approach must be taken to gather data for this cost element and cost elements 3.1.2.1 and 3.1.2.3. The analyst must obtain a list of the fiber optic component requirements for a specific task from an aircraft manufacturer. This fiber optic component list can then be priced with the use of the cost data received from the fiber optic industry via the Delphi Questionnaire in Appendix L or actual catalog prices.

The Delphi Questionnaire in Appendix L would be forwarded to the fiber optic manufacturer/R&D activities found in the NELC composite distribution list.

OTHER MATERIAL

A somewhat different approach must be taken to gather data for this cost element and cost elements 3.1.2.1 and 3.1.2.2. The analyst must obtain a list of the fiber optic component requirements for a specific task from an aircraft manufacturer. This fiber optic component list can then be priced with the use of the cost data received from the fiber optic industry via the Delphi Questionnaire in Appendix L or actual catalog prices.

The Delphi Questionnaire in Appendix L would be forwarded to the fiber optic manufacturers/R&D activities found in the NELC composite distribution list.

SUSTAINING ENGINEERING

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for this cost data would be aircraft manufacturer familiar with the engineering requirements of modifications and field changes.

Delphi Questionnaire sections I, II and V are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question V-2 will produce the required cost data.

3.1.6.2

SITE/SHIP/VEHICLE CONVERSION

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for this cost data would be aircraft manufacturers familiar with aircraft conversion to update to a new technology.

Delphi Questionnaire sections I, II and V are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question V-3 will produce the required cost data.

ASSEMBLY, INSTALLATION AND CHECKOUT

This is a Category I cost element which will use the Delphi Questionnaire technique to obtain cost data. The source for this cost data would be aircraft manufacturers familiar with aircraft conversion to update to a new technology.

Delphi Questionnaire sections I, II and V are applicable to this cost element and would be forwarded to the aircraft manufacturers. Question V-4 will produce the required cost data.

3.1.8

GENERAL AND ADMINISTRATIVE

The data required for this cost element will be the same as the cost data obtained for cost element 2.1.12. The analyst can use the cost data produced by Delphi Questionnaire section IV, question IV-5 to fulfill the requirements of this cost element.

OTHER OPERATIONS COSTS

This element represents the annual opportunity cost associated with either alternative when the A-7 weapons system becomes inoperable due to the N/WDS interconnect system. Opportunity costs attempt to measure the opportunity which is lost or sacrificed when a choice of action precludes another. For example, there are several costs associated with an inoperable aircraft. First, there are the direct/indirect support costs to repair and restore the aircraft to an operable condition. Second, there are those costs associated with the missions not flown or the training not received, during the period the aircraft is inoperable. Most life cycle cost models recognize and account for the direct costs associated with aircraft downtime; but neglect the opportunity costs involved. This could be due to the difficulties associated with quantification of opportunity costs or the structure of the cost-benefit model.

Opportunity costs are difficult to measure becasuse they may indeed represent different costs to different decision makers. For example, the cost of missing a training mission would intuitively be less than the cost of missing a scheduled wartime strike mission. Force level planners often recognize lost mission opportunity costs by increasing the number of forces to ensure the desired mission results. The A-7 ALOFT coax/fiber optic alternative systems are

systems are specified as functional equivalents, and will probably have different mission reliabilities associated with them. Because of this, the life cycle costs are not directly comparable because one system will operate more frequently then the other. In addition, since a cost decision model whould provide the decision maker with all relevant costs which impact the decision (such as the affect of reliability on total life cycle costs) as opportunity cost element, computed in an identical manner for each alternative, is required.

Several methods to quantify opportunity costs were considered. The following method suggested by Professor C. R. Jones of the Naval Postgraduate School was selected:

It is assumed that at the time of the procurement decision, that the net present value of the weapon system's effectiveness is equal or greater than the procurement costs. In formula terms this is:

$$C \leq \int_{o}^{T} E(t)\, e^{-it}\, dt \qquad (1)$$

where: $E(t)$ = the weapon systems effectiveness timestream from time zero to time T, its planned service life.

C = A-7 weapon system unit procurement cost

i = interest rate.

Now, if the weapon system is assumed to have an equal average annual effectiveness, denoted by $\overline{E}$, then,

$$C \leq \bar{E} \int_{o}^{T} e^{-it} dt = \frac{\bar{E}}{i}(1-e^{-it})$$

or

$$\frac{iC}{(1-e^{-iT})} \leq \bar{E} \quad (2)$$

Therefore, at the time of the procurement decision, the average annual weapon system effectiveness is at least worth,

$$\bar{E} = \frac{iC}{1-C^{-iT}}$$

Accordingly, $\bar{E}$ can also be used as a measure of the cost of not having the capability. Cost element 4.1.6 is, therefore, defined for either alternative as:

$$O_{1t} = N_t \bar{E}$$

$$= \frac{N_t \, i \, C}{1-e^{-iT}}$$

where: N_t = aircraft years of downtime due N/WDS system in year t, for the alternative

t = 1 ... 10

C = A-7 unit procurement cost

T = A-7's expected service life

and i = discount or interest rate.

ORGANIZATIONAL MAINTENANCE PERSONNEL

The TRI-TAC office has developed the following cost formula to calculate the cost of this element. Since the hourly cost of organizational maintenance personnel can and will vary, it is recommended that the latest personnel costs ber verified with the office of the Chief of Naval Personnel.

COST FORMULA

$$\begin{bmatrix}\text{ORGANIZATIONAL}\\\text{MAINTENANCE}\\\text{PERSONNEL}\\\text{COST}\end{bmatrix} = \left[\begin{bmatrix}\text{PREVENTATIVE}\\\text{MAINTENANCE}\\\text{TIME}\end{bmatrix} + \begin{bmatrix}\text{CORRECTIVE}\\\text{MAINTENANCE}\\\text{TIME}\end{bmatrix}\right] \times \begin{bmatrix}\text{COST OF}\\\text{ORGANIZATIONAL}\\\text{MAINTENANCE}\\\text{PERSONNEL}\\\text{PER/HOUR}\end{bmatrix} \times \begin{bmatrix}\text{QUANTITY OF}\\\text{OPERATIONAL}\\\text{EQUIPMENT}\end{bmatrix}$$

WHERE:

$$\begin{bmatrix}\text{CORRECTIVE}\\\text{MAINTENANCE}\\\text{TIME}\end{bmatrix} = \begin{bmatrix}\text{NUMBER OF}\\\text{OPERATING HOURS}\\\text{PER YEAR}\end{bmatrix} \times \frac{\begin{bmatrix}\text{MEAN TIME}\\\text{TO REPAIR}\end{bmatrix}}{\begin{bmatrix}\text{MEAN TIME}\\\text{BETWEEN FAILURES}\end{bmatrix}}$$

COST FACTORS	UNITS
PREVENTATIVE MAINTENANCE TIME**	HOURS/YR.
CORRECTIVE MAINTENANCE TIME**	HOURS/YR.
NUMBER OF OPERATING HOURS PER YEAR	HOURS/YR.
MEAN TIME TO REPAIR	HOURS
MEAN TIME BETWEEN FAILURES	HOURS
COST OF ORGANIZATIONAL MAINTENANCE PERSONNEL PER HOUR	$/HOUR
QUANTITY OF OPERATIONAL EQUIPMENT	UNITS

**MAINTENANCE TIME SHOULD BE ADJUSTED TO INCLUDE TIME REQUIRED FOR DOCUMENTATION SUCH AS MAINTENANCE RECORDS AND SUPPLY TRANSACTION RECORDS.

SUPPORT EQUIPMENT MAINTENANCE

Historical data analysis has shown that the cost of support equipment maintenance can be approximated by a factor of 10 percent of the equipment cost. The TRI-TAC office has developed the following cost formula to calculate the cost of this element.

COST FORMULA

$$\begin{bmatrix}\text{SUPPORT}\\ \text{EQUIPMENT}\\ \text{MAINTENANCE}\\ \text{COST}\end{bmatrix} = \begin{bmatrix}\text{SUPPORT}\\ \text{EQUIPMENT}\\ \text{MAINTENANCE}\\ \text{FACTOR}\end{bmatrix} \times \begin{bmatrix}\text{COST OF COMMON AND}\\ \text{PECULIAR SUPPORT}\\ \text{EQUIPMENT}\end{bmatrix}$$

COST FACTORS	VALUE	UNITS
SUPPORT EQUIPMENT MAINTENANCE FACTOR	10%	PERCENT
COST OF COMMON AND PECULIAR SUPPORT EQUIPMENT		$

SPARE PARTS AND REPAIR MATERIAL

Based upon a 5 percent estimator the following cost formula was developed by the TRI-TAC office.

COST FORMULA

$$\begin{bmatrix}\text{SPARE PARTS}\\ \text{AND}\\ \text{REPAIR MATERIAL}\end{bmatrix} = \begin{bmatrix}\text{INVENTORY}\\ \text{REPLENISHMENT}\\ \text{COST FACTOR}\end{bmatrix} \times \begin{bmatrix}\text{EQUIPMENT}\\ \text{UNIT}\\ \text{PRODUCTION}\\ \text{COST}\end{bmatrix} \times \begin{bmatrix}\text{QUANTITY OF}\\ \text{OPERATIONAL}\\ \text{EQUIPMENT}\end{bmatrix}$$

COST FACTORS	VALUE	UNITS
INVENTORY REPLENISHMENT COST FACTOR	5%	PERCENT/YR
EQUIPMENT UNIT PRODUCTION COST		$/UNIT
QUANTITY OF OPERATIONAL EQUIPMENT		UNITS

INVENTORY MANAGEMENT

The cost of item inventory management is not directly dependent upon the type of item or the associated technology. Inventory management cost is indirectly dependent upon the item and associated technology through the item cost and the number of new items entered into the inventory.

The TRI-TAC office has developed the following cost formula to calculate the cost of this element.

COST FORMULA

$$\begin{bmatrix}\text{INVENTORY}\\ \text{MANAGEMENT}\\ \text{COST}\end{bmatrix} = \begin{bmatrix}\text{NUMBER OF}\\ \text{NEW FSN}\\ \text{ITEMS}\end{bmatrix} \times \frac{\begin{bmatrix}\text{FSN ITEM}\\ \text{1ST YEAR}\\ \text{COST}\end{bmatrix} + \begin{bmatrix}\text{FSN ITEM}\\ \text{RECURRING}\\ \text{COST}\end{bmatrix} \times \begin{bmatrix}\text{NUMBER OF}\\ \text{YEARS PER} - 1\\ \text{LIFE CYCLE}\end{bmatrix}}{\begin{bmatrix}\text{NUMBER OF}\\ \text{YEARS PER}\\ \text{LIFE CYCLE}\end{bmatrix}}$$

COST FACTORS	VALUE	UNITS
NUMBER OF NEW FSN ITEMS		ITEMS
FSN ITEM 1ST YEAR COST	FROM CHART BELOW	$/ITEM
FSN ITEM RECURRING COST	FROM CHART BELOW	$/ITEM/YEAR
NUMBER OF YEARS PER LIFE CYCLE		YEARS

INVENTORY LINE ITEM MANAGEMENT COSTS

FSN DOLLAR VALUE	INTRODUCTION COSTS	FIRST YEAR COST*	ANNUAL RECURRING COSTS
$25,000 – OVER	$680	$1070	$720
$10,000 – $24,999	530	770	420
$ 2,500 – $ 9,999	450	580	130
UNDER – $ 2,500	430	460	110
WEIGHTED AVERAGE	480	510	160

*INCLUDES INTRODUCTION COST

APPENDIX L

AIRCRAFT INDUSTRY DELPHI QUESTIONNAIRE

SECTION I **RESPONDENT IDENTIFICATION**

Organization or Firm Name ______________________

Respondent* Name ______________ Position Title ______________

Business Address ______________ ______________ Phone No. ______________

Years in Present Position ________ Years in Present Occupation ________ Years in the Industry ________

Would you be willing to discuss the questionnaire with an interviewer? ( ) Yes ( ) No

* If additional personnel assist in completing this questionnaire enter their name(s) by the applicable question(s).

SECTION II

FIBER OPTICS PERFORMANCE CHARACTERISTICS

This section lists the general Fiber Optics Performance Characteristics which fiber optics cable posses but are lacking in equivalent coax cable designed to perform a simular task.

HIGH TEMPERATURE TOLERANCE

Temperatures up to approximately 150^{O}C can be tolerated by fiber optic cable.

VIBRATION TOLERANCE

Fiber optic cable can tolerate vibration without experiencing electrical problems, such as internal cable short circuits or changing electrical conducting characteristics.

NO CROSS TALK

Adjacent cables within a cable bundle or cable harness are not susceptible to stray signals induced do to their close proximity.

RFI/EMI/NOISE IMMUNITY

External electrical signals do not adversely affect the light signal within a fiber optic cable. There is no electrical signal to be either radiated or be susceptible to stray electrical signals.

TOTAL ELECTRICAL ISOLATION

There is no electrical current path within a fiber optic cable. This characteristic allows interconnected equipments to be electrically isolated from each as well as isolated from the interconnecting cables.

NO SPARK/FIRE HAZARD

The total lack of electric current within the fiber optic cable reduces the potential for spark generation to zero. This has a direct impact upon combustible ignition caused by sparks.

NO SHORT CIRCUIT LOADING

Since fiber optic cables do not carry electric current, damage to a cable could not cause an electrical signal reflection back to an equipment, which could cause an equipment failure.

EMP IMMUNITY

Similar to the RFI/EMI/NOISE immunity, nuclear radiation does not have a severe impact upon fiber optic cable.

NO CONTACT DISCONTINUITY

A light signal does not require a physical contact at signal connector interfaces, it can pass through an air gap.

WIDE SIGNAL BANDWIDTH

Fiber optic cable has a wider bandwidth than either the present twisted pair cable or installed coax cable, however the LED is the limiting factor for signal bandwidth.

CORROSION RESISTANT

Common but severe environmental characteristics which affect electrical signal carrying cable have little or no affect upon the fiber optic cable signal quality.

HIGH SECURITY

Fiber optic cable does not have the adverse characteristic which would allow it to radiate a signal that could be coupled and picked up in a non-secure environment.

SMALL SIZE

The diameter of present and the future fiber optic cable is equal to or less than that of an equivalent use coax cables.

LIGHT WEIGHT

Fiber optic cable is lighter weight than an equivalent use coax cable.

REDUCED SAFETY HAZARD

The high temperature tolerance and no spark hazard characteristics coupled together allow fiber optic cable immunity to exclusion from location in a hazardous area.

REDUCED ELECTRICAL POWER REQUIREMENTS

Fiber optic light transmitting and receiving modules have the potential to require less electrical power to operate than an equivalent coax cable system.

SECTION III

RESEARCH AND DEVELOPMENT COSTS

Research and Development costs refer to all costs associated with the research, development test and evaluation of the system or equipment. This includes all costs during concept initiation, validation and full scale development.

SCENARDIO

Your firm has contracted with the Government for a twofold Research and Development effort involving;

(1) design of a new Navy fighter aircraft with the stipulation that all electrical signal carrying wiring will be eliminated and fiber optic cable will be substituted.

(2) redesign of an existing Navy fighter aircraft electrical signal interconnect cable system. All existing electrical signal carrying wiring will be replaced with fiber optic cable.

The new fiber optic cable will no longer be a point-to-point connection. In both of the above situations, the fiber optic cable will carry a multiplexed light signal.

In order to standardize all questionnaire responses assume that if fiber optic cable was not available, each of the above efforts would be completed using coaxial cable. Knowing the anticipated advantages of fiber optic cable over coaxial cable listed in section II, answer the following questions and indicate your qualifications to answer each question.

SECTION III-1

Given the potentially fiwer restrictions of fiber optic cable compared to coax, would the electrical cabling design engineering effort using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the design engineering required if using coax? If either GREATER or LESS, BY what fraction?

( ) GREATER THAN

( ) LESS THAN

( ) EQUAL TO

____
Fractional Difference

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION III-2

With the operationally unproven fiber optic performance characteristics would your development test effort on a prototype model using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the development test effort if using coax? If either GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ______________________ Fractional Difference

( ) EQUAL TO

What are your qualifications to answer the question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION III-3

Based upon your previous experience with Government Development Test and Evaluation (DTE) programs conducted during Research and Development and the fiber optics performance characteristics, would your support of Government DTE using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the support required if using coax? If either GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ______________________ Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION III-4

Assume that fiber optic cable is installed in aircraft as signal carrying conductors in place of coax cable. Would the design engineering effort to develop peculiar support equipment for a fiber optic installation be GREATER THAN, LESS THAN or EQUAL TO the design engineering required to develop similiar equipment for a coax cable installation? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN

( ) EQUAL TO

____
Fractional Difference

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION III-5

What is the rate used to apply the cost of General and Administrative (G&A) expenses to Government Research and Development contracts of the type noted in the section III scenario? To which costs is this rate applied?

G&A RATE: ____________

G&A APPLIED TO: ____________________________

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ________________________

COMMENTS:

SECTION IV

NON-RECURRING INVESTMENT COSTS

Non-recurring investment costs refer to those costs incurred beyond the program development phase, which are one time costs incurred during a program production phase.

SCENARIO

Your firm has contracted with the Government for a two phase production effort involving:

(1) modification of an existing Navy fighter aircraft by replacing all electrical signal interconnect cable with fiber optic cable.

(2) production of a new Navy figher aircraft using fiber optic cable as the signal interconnect medium for all signal carrying cables.

The fiber optic cable will not be a point-to-point connection. In both of the above situations, the fiber optic cables will carry a multiplexed light signal.

In order to standardize all questionnaire responses assume that if fiber optic cable was not available, each of the above efforts would be completed using coaxial cable. Knowing the anticipated advantages of fiber optic cable over coaxial cable listed in section II, answer the following questions and indicate your qualifications to answer each question.

SECTION IV-1

Knowing the performance characteristics of fiber optics listed in section II, would the one time investment in manufacturing support equipment required for a production effort using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the investment in similar equipment if using coax cable? If either GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN   ____________________ Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ____________________

COMMENTS: ____________________

SECTION IV-2

Assume that the Government does not conduct an Operational Test and Evaluation (OTE) program to further verify the performance characteristics of fiber optics. Based on your previous experience with Government OTE programs what FRACTION of OTE technical support costs would be saved by using fiber optics in place of coax cable?

FRACTION OF COST SAVED ____________________

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name

COMMENTS:

SECTION IV-3

Knowing the fiber optic performance characteristics listed in section II and the fact that the appropriate Navy maintenance personnel have a basic knowledge of coax cable systems, would a fiber optics maintenance program effort be GREATER THAN, LESS THAN or EQUAL TO a similar program if teaching coax cable maintenance procedures? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ______________________
Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION IV-4

Assume that fiber optic cable is installed in aircraft as signal carrying conductors in place of coax cable. Would the production cost of peculiar support and test equipment for a fiber optic installation be GREATER THAN, LESS THAN or EQUAL TO the production cost for similar equipment for a coax cable installation? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ____________________ Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ____________________

COMMENTS:

SECTION IV-5

What is the rate used to apply the cost of General and Administrative (G&A) expense to Government production contracts of the type noted in the section IV scenario? To what costs is the rate applied?

G&A RATE: ____________

G&A APPLIED TO: ______________________________

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________________

COMMENTS:

SECTION V

RECURRING INVESTMENT COSTS

Recurring investment costs include those production costs that recur with each unit produced. These costs tend to be subject to a learning curve concept in which the cost per unit decreases as quantity increases.

SCENARIO

Your firm has contracted with the Government for a two phase production effort involving:

(1) modification of existing Navy fighter aircraft by replacing all electrical signal interconnect cable with fiber optic cable,

(2) production of a new Navy fighter aircraft using fiber optic cable as the signal interconnect medium for all signal carrying cables.

The fiber optic cable will not be a point-to-point connection. In both of the above situations, the fiber optic cables will carry a multiplexed light signal.

In order to standardize all questionnaire responses assume that if fiber optic cable was not available, each of the above efforts would be completed using coaxial cable. Knowing the anticipated advantages of fiber optic cables over coaxial cable listed in section II, answer the following questions and indicate your qualifications to answer each question.

SECTION V-1

Being experienced in aircraft production, and knowing the fiber optics performance characteristics listed in section II, would manufacturing costs using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the manufacturing costs if using coax cable? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ______________________ Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION V-2

Given the performance characteristics of fiber optic cable, would the engineering effort applied to future aircraft modifications and field changes if using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the engineering effort required if using coax cable? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ______________________

Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION V-3

Using any Navy fighter aircraft with which you are familiar and knowing the fiber optic performance characteristics, would the cost to convert the actual aircraft to accomodate fiber optic cable be, GREATER THAN, LESS THAN or EQUAL TO the cost of a similar conversion if using coax cable? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN

( ) EQUAL TO

________________ Fractional Difference

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________

COMMENTS:

SECTION V-4

After completing the conversion addressed in the previous question (V-3) would the cost of systems checkout using fiber optic cable be GREATER THAN, LESS THAN or EQUAL TO the cost of a similar effor if using coax cable? If GREATER or LESS, by what fraction?

( ) GREATER THAN

( ) LESS THAN ______________________ Fractional Difference

( ) EQUAL TO

What are your qualifications to answer this question?

(1) HIGHLY QUALIFIED TO (5) POORLY QUALIFIED ( )

Respondent Name ______________________________

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